THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME XIX — JUNE 1904 — NUMBER 5

ON A POSSIBLE VARIATION OF THE SOLAR RADIATION AND ITS PROBABLE EFFECT ON TERRESTRIAL TEMPERATURES.[1]

By S. P. LANGLEY.

INTRODUCTION.

THE purpose of the present communication is primarily to discuss the validity of a surmise we may entertain, founded on observations here, as to certain possible changes in the solar constant. There is especially discussed a possible falling off of solar radiation about the close of March 1903, as indicated by certain recent values of solar radiation computed from observations here, and compared with actually observed temperatures for eighty-nine stations of the North Temperate Zone.

I. METHODS OF OBSERVATION AND CONSIDERATIONS GOVERNING THE ADMISSION OR REJECTION OF EXPERIMENTAL DATA.

The determination of the solar radiation toward the Earth, as it might be measured outside the Earth's atmosphere (called the "solar constant"), would be a comparatively easy task, were it not for the almost insuperable difficulties introduced by the

[1] Reference may be made to the writer's paper in the ASTROPHYSICAL JOURNAL for March 1903, and to Mr. C. G. ABBOT'S paper in *Smithsonian Miscellaneous Collections* (Quarterly Issue), **45**, 74–83, 1903.

actual existence of such an atmosphere, above which we cannot rise, though we may attempt to calculate what would be the result if we could. The determinations of the so-called solar constant, then, chiefly depend on various methods of eliminating the effects of the terrestrial atmospheric absorption, since only after the actual interposition of this we receive the Sun's heat.

These determinations depend principally on two classes of observations:

First, on getting as far above this atmosphere as possible, by the actual ascent of a lofty mountain, and by the observation of the solar radiation there with a subsequent comparison with that nearer its base. This method possesses great advantages over any other, but presents obvious difficulties in the execution.[1]

The second principal class of observations, and the only one considered here, is restricted to a single station, which we must usually take in a low altitude like that at Washington. It consists in making measurements (1) by the actinometer, of the total radiation observed; (2) of the intensity of homogeneous rays in different parts of the solar spectrum for different altitudes of the Sun. (3) From these direct observations we can in theory calculate the total absorption of the atmosphere from the evidence gathered by the spectrobolometer as to that of the several rays for different altitudes of the Sun and for different thicknesses of air.

As our atmosphere and its absorption is in a condition of incessant fluctuation, it will always be hard to discriminate between changes due to it and those, if any, due to an actual change in the radiation of the Sun itself; and this discrimination constitutes the particular difficulty of the present research.

The present discussion will lead us to estimate the validity of any surmise as to the actual changes in the solar constant, founded on such observations as those of the second class.

As for the accuracy of the actinometer measures of total solar radiation at the Earth's surface, it is easy to obtain measures relatively exact, within about 2 per cent., or perhaps even less.

[1] For an example of it the reader is referred to the account of the writer's expedition to Mount Whitney, *Professional Papers*, U. S. Signal Service, No. XV.

But the absolute standardization of the instrument offers uncertainty of quite another order, so that I do not think that the absolute magnitudes of the results to be presented here are necessarily within 20 per cent. of the truth, or even more.

The homogeneous rays are observed here by the bolometer, and the bolographic curves from which the atmospheric extinction of radiation is inferred, traced by the movement of the spot of light upon the galvanometer scale, are now very much more satisfactory than formerly. They represent an immense gain over the conditions operating when I began the work at Allegheny. The light-spot should move only by an impulse from the Sun, but, owing to extraneous causes, it was at first frequently impossible to keep it upon the scale of the galvanometer during so short a time as a single minute. The apparatus now, however, operates so well that such drift and tremor is relatively unknown, and the zero of the galvanometer is found almost unchanged for weeks together—a gain due to many causes and successive improvements during many years, from my own and other hands, but to which none have contributed more than Mr. Abbot, of this Observatory. Measurement and reduction of a series of from five to ten bolographs of a single day requires, however, so much labor that a single computation of the solar constant takes about one week.

It is of course the third branch of the inquiry, namely, the calculation of total atmospheric absorption from the bolometric measures, which offers the chief, and perhaps insurmountable, uncertainty. The measures on the extinction of homogeneous rays are assumed to be expressed by a logarithmic formula as follows:

$$\log d = m \log a + \text{constant} \;,$$

in which d is the ordinate of the bolographic energy-curve corrected for instrumental absorption, m the air mass (proportional to the secant of the zenith distance of the Sun for moderate inclinations), and a the assumed transmission of the atmosphere for vertical incidence. If a is constant during the period of observation, the expression is in the form of the equation of a straight line, the tangent of whose inclination is log a. Accord-

ingly the measures of a single day, for separate wave-lengths, are plotted[1] with log d as ordinates, and m as abscissæ, and from these plots the values of a are determined. The logarithmic formula is itself immediately derived from the exponential formula of Bouguer, which, for constant barometric pressure and homogeneous rays, may be written

$$e = e_0 a^m ,$$

where e is the energy of the ray observed at the Earth's surface, e_0 its energy outside the atmosphere. Since d, the corresponding ordinate of the bolographic curve, is proportional to the energy of the ray, we may write

$$d = d_0 a^m \ , \quad \text{and } d_0 = \frac{d}{a^m} \ ,$$

where d_0 is the ordinate of the bolographic curve corrected for atmospheric transmission.

Thus assuming that we know a, and knowing m, we may immediately determine corrected ordinates representing the bolographic curve outside the atmosphere. The total area under such a curve is proportional to the total energy of all wave-lengths, so that the ratio of the area of the curve outside the atmosphere to the area of the curve at the Earth's surface is the correcting factor to be applied to the solar radiation as observed at the surface of the Earth, to give the value of solar radiation outside the atmosphere.

As remarked by the writer at p. 147 of the Report of the Mount Whitney Expedition:

If the absorption were invariable at all hours of the day and for all parts of the Earth situated at the same height above the sea and subjected to the same air-pressure, the comparison of high and low Sun observations would give us the true energy outside the air, whether the absorbent material were distributed uniformly throughout the atmosphere or were gathered into horizontal layers superposed according to any law whatever. The character of the atmosphere interposed between us and the Sun, however, is constantly varying through the day, and even if it were at rest, a vertical section would have a different composition from that made at a very great inclination, which would necessarily pass over portions of the Earth's surface subjected to conditions very different from those existing at the place of observation.

[1] The plots here shown are borrowed from the *Smithsonian Miscellaneous Collections.*

These observations apply to the methods of reduction now employed, but owing to the increased accuracy of observation, due to the great improvements of apparatus, and especially to the writer's introduction of the automatic or so-called bolographic recording devices, it is no longer necessary to follow the Sun very long or to very great zenith distances to obtain differences of ordinates of the bolographs measurable with sufficient exactness. The determinations are now chiefly made between the hours of 1 and 4 P. M., and it is only the air which transmits the rays during this interval whose uniform transparency is in question. While the atmosphere extends to an indefinite elevation, the portions within a few miles of the Earth's surface contain almost all the variable constituents of it, and the path of the ray in these lower layers does not sweep over a very large extent of the Earth's surface between the hours of 1 and 4 P. M.

The following table, computed for the times of the equinoxes, gives the areas of the Earth's surface over which the lower air-layers must remain unaltered in transparency during the observations, if good results are to be obtained:

Area over which Constant Transparency is Required	In the Air-Layer below an Elevation of
0.03 sq. miles	1/5 mile
0.86 "	1 "
3.0 "	2 "
6.8 "	3 "
12.1 "	4 "
304.0 "	20 "

As nearly all the clouds, water vapor, and other variable constituents of the atmosphere are contained in the layers below a two-mile elevation, it is immediately seen that the region over which approximately constant conditions must, for good observations, continue for three hours is not many square miles, and this is a demand which can ordinarily be approximately met.

Nevertheless, it is obvious that if there was no criterion as to whether constant conditions had prevailed during the measurements, the mere smallness of the period of time and of the area

concerned would be of little weight for inference of the value of the resulting solar constant.

There are various kinds of evidence to be derived from the measures themselves, which aid in forming a judgment of their value for determining the constant, and enable us to reject certain days' observations which the impressions of the eye alone as to the clearness of the air might have inclined us to retain. These evidences are principally as follows:

1. The bolographic measurements of a single day on homogeneous rays, when plotted logarithmically, as already described, should be represented closely by straight lines, if the air and instrumental conditions are nearly invariable. Examples of good results of this kind are shown in the accompanying figure, which gives for March 25 and 26, 1903, the observations and representative lines for wave-lengths 1.027μ, 0.656μ, 0.468μ, and 0.395μ.[1]

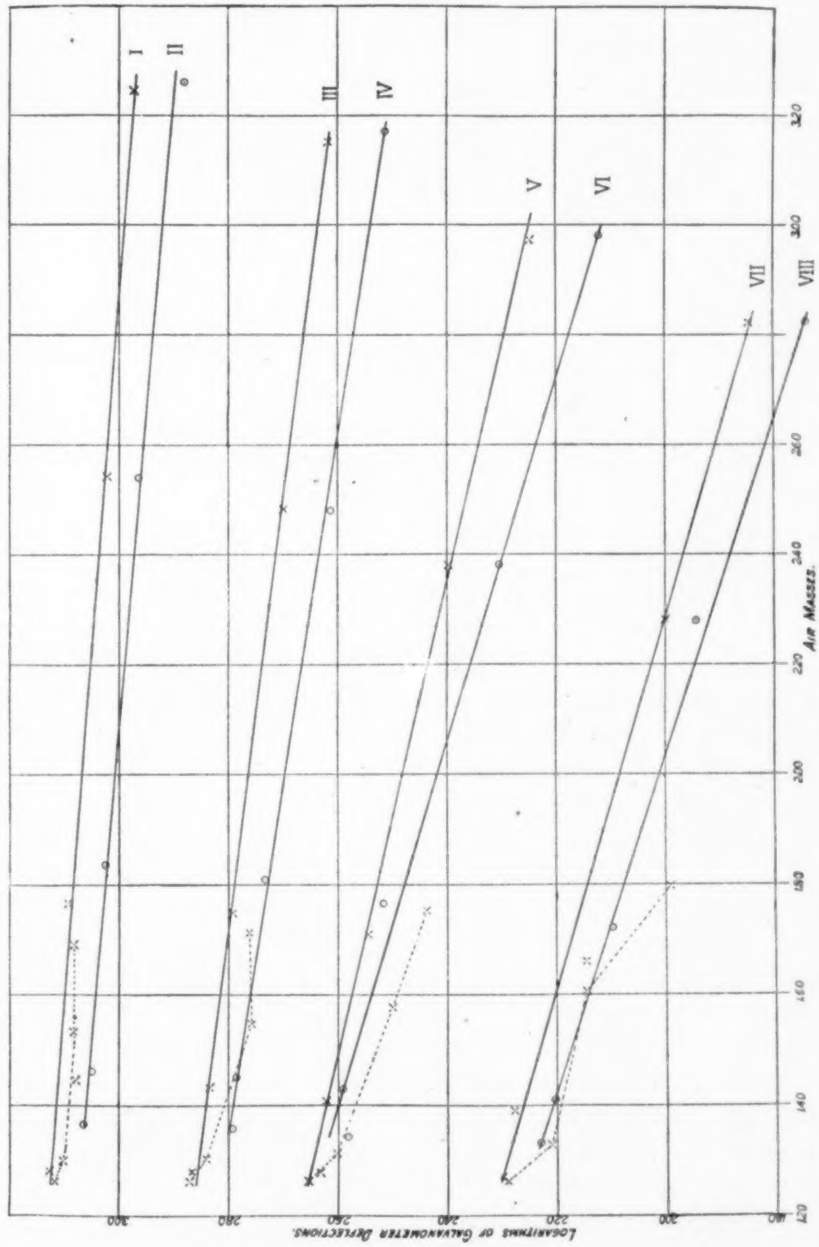
2. The area of the (calculated) spectrum energy-curve outside the atmosphere ought to be nearly the same whether estimated from one or another bolograph of a given date. As examples of this and the two following criteria, the reader is invited to consult the table of solar constant values on a later page.

3. The several solar-constant values computed for a given date ought to agree within the limits of experimental error, though depending on independent bolographs and pyrheliometer measures.

4. If no variation of solar radiation occurs over several months, all the values of the solar constant computed during that interval should agree within close limits, regardless of alterations in the transparency of the atmosphere and the altitude of the Sun which may have intervened. In this connection the reader's attention is invited to the values of August, October, and December 1903.

5. As the great bands of the infra-red are presumed to be

[1] The dotted portions of the lines of March 26 are for morning observations. As it is seldom found that the morning observations bear this test of uniformity of conditions of the atmosphere, they are now omitted, and the transmission coefficients are based on the afternoon bolographs alone.



TRANSPARENCY OF THE ATMOSPHERE FROM BOLOGRAPHIC OBSERVATIONS.

FIG. 1.

solely atmospheric, they should disappear in the energy-curve outside the atmosphere. Accordingly, the same result should be reached by the extrapolation in these regions, whether we determine a transmission coefficient at the bottom of the bands themselves, or from the smoothed curve above them. It appears from studies of Mr. Fowle, of the Astrophysical Observatory, that such is the case, except for the very deepest bands, where the determination is subject to many kinds of error all known to tend in the same direction.

The coincidence of all these kinds of evidence does not, however, in the writer's belief, give absolute assurance that the values of the solar radiation may not be underestimated, a defect inherent in the method of observation at a single station.

We cannot go outside the atmosphere and prove that our determinations of its absorption are correct, but, at all events, the results are the best that can be reached at present from our single and low station. We may next consider their numerical values, and what they appear to show.

II. EXPERIMENTAL RESULTS.

1. *Atmospheric transmission.*—In the following table are given the atmospheric transmission coefficients for rays of certain wave-lengths for separate days of 1903–4, and the mean of numerous similar observations of 1901–2. It is to be remembered that these determinations are made only on the most cloudless days, so that they represent a transparency probably above the normal, though they do not include data of days when cumulus clouds were frequent, such as are often associated with a very deep blue intervening sky.

Attention has already been drawn by the writer[1] to the diminished transparency during the early months of 1903 as compared with 1901–2. The reader will now observe that this condition appears not to have continued so marked during the last three months of 1903, although the transparency did not recover fully its maximum value of 1901–2.

It seems probable that such long-continued alterations of

[1] *Nature*, November 5, 1903.

TABLE I.

Atmospheric Transmission of Radiation for Zenith Sun.

Date	Percentage Transmission for Vertical Rays										
	$0^{\mu}.40$	$0^{\mu}.45$	$0^{\mu}.50$	$0^{\mu}.60$	$0^{\mu}.70$	$0^{\mu}.80$	$0^{\mu}.90$	$1^{\mu}.0$	$1^{\mu}.2$	$1^{\mu}.6$	$2^{\mu}.0$
1903, Feb. 19	67	64	66	72	76	80	83	85	86	90	92
26	48	60	66	68	74	83	88	90	93	93	92
Mar. 3	40	48	66	73	79	84	87	89	92	96	96
25	47	50	57	66	72	76	79	81	84	88	89
25	52	58	62	68	77	80	81	83	85	89	90
Apr. 17	55	60	69	77	80	82	87	90	94	97	97
28	39	52	56	64	71	74	76	78	82	88	89
29	46	49	56	66	72	76	77	80	83	88	90
July 7	42	60	66	69	77	82	85	86	88	89	86
Aug. 24	39	52	60	59	78	84	86	87	89	90	89
Sept. 14	52	76	81	82	87	90	91	91	93	94	94
Oct. 14	64	70	76	80	85	88	89	91	91	(92)	(92)
29	52	59	65	75	80	82	84	85	88	91	(91)
Dec. 7	58	67	76	81	84	87	89	92	93	95	(94)
23	67	71	75	80	86	89	90	91	92	94	(94)
1904, Jan. 27	60	67	73	73	79	84	89	91	91	(91)	(91)
Feb. 11	42	55	58	59	70	78	84	89	92	95	(94)

Mean Results.

1903, Feb.–Aug.	47.5	55.3	62.4	68.2	75.6	80.1	82.9	84.9	87.6	90.8	91.0
1903–4, Sept–Feb.	56.4	66.3	72.0	75.7	81.6	85.4	88.0	90.0	91.4	93.1	93.0
1903–4	51.2	59.8	65.2	70.1	78.1	82.3	85.0	87.0	89.2	91.8	91.6
1901–2	....	....	76.5	76.9	85.7	89.7	91.0	92.1	93.3	93.0	95.0

atmospheric transparency, if general over considerable areas of the Earth's surface, might directly influence observed temperatures, for if the air becomes more opaque, correspondingly less direct solar radiation remains in the beam to be absorbed at the Earth's surface, so that diminished surface temperatures naturally follow. It is of course quite possible that in so complicated a thing as climate other factors may tend to reduce such direct effects, but these are not immediately apparent.[1]

[1] An effect of diminished atmospheric transparency upon plant growth seems equally probable; for it is generally conceded that certain functions of plant growth depend on a supply of violet radiations. It will be seen that the defect of atmospheric transparency noted in the early months of 1903 tended to reduce the intensity of the violet end of the spectrum most strongly. It would be of much interest to know if such a deficiency of violet rays may not have appreciably affected vegetation during this period.

As for the causes of the increased opacity of the atmosphere, nothing positive is certainly known, though some have surmised that the many and long-continued volcanic eruptions of 1902 may have distributed more fine dust than usual in the air. It can, on the other hand, be more definitely stated that the defect of transparency was not caused by increased water vapor; for the inferior transparency was observed on several of the dryest days on record, as shown by the form of the great water-vapor absorption bands in the infra-red spectrum.

2. *Solar radiation outside the atmosphere.*—The following table includes the best determinations of the solar radiation outside the atmosphere, made at the Smithsonian Observatory from October 1902, to March 1904. A part of these were included in Mr. Abbot's paper, above referred to, but as additional computations and data are given for several of the days, they are here repeated.[1] As was stated on an earlier page, the values are not regarded as absolute measures of the solar constant, but only as forming a series comparable among themselves, from which all known terrestrial variations are excluded, and which may furnish evidence of a suspected variability of the solar radiation.

Column 9, giving the radiation outside the atmosphere, is derived by multiplying the radiation at the Earth's surface, given in column 7, by the ratio of the area of the energy-curve outside the atmosphere to that at the Earth's surface, as given in columns 6 and 5, and correcting to mean solar distance by column 8. As already said, the agreement, both in columns 6 and 9, of the two computations of the same day furnishes two checks on the goodness of the day's work. Different instrumental conditions may, however, alter the values in column 6 as between different days.

It will be seen that the days of observation during 1903 fall in two groups, yielding high values and low values of solar radiation respectively, the former including all days prior to March 26, and the latter all days subsequent to that date. A possible return to the higher values is indicated by the observations of February 11, 1904, but we must await subsequent measures to confirm this.

[1] The values of March 3, April 17, and April 28, included in Mr. Abbot's paper, are here omitted, because the observations of those days are of little weight.

TABLE II.

Measures of the "Solar Constant."

1	2	3	4	5	6	7	8	9
Date	Character of Observations	Hour Angle West	Air Mass	Area of Energy Curve: At Earth's Surface	Area of Energy Curve: Outside Atmosphere	Total Radiation at Earth's Surface (Calories per cm per Minute)	Correcting Factor for Solar Distance	Total Radiation Outside Atmosphere Corrected to Mean Solar Distance (Calories per cm per Minute)
1902, Oct. 9......	Fair	$0^h\ 06^m$	1.42			1.42	0.994	2.19
15......	Fair	1 31	1.62			1.44	0.989	2.19
22......	Fair	3 01	2.41			1.30	0.985	2.16
1903, Feb. 19......	Good	1 01	1.64	243	423	1.35	0.975	2.28
19......	Good	2. 22	2.00	224	431	1.20	0.975	2.25
Mar. 25......	Excellent	2 01	1.45	186	355	1.19	0.996	2.26
25......	Excellent	3 52	2.50	137	365	0.83	0.996	2.21
26......	Excellent [1]	1 57	1.44	209	380	1.16	0.997	2.10
26......	Excellent	2 59	1.75	200	398	1.05	0.997	2.08
Apr. 29......	Excellent	1 39	1.18	219	377	1.11	1.018	1.94
29......	Excellent	2 26	1.31	202	370	1.05	1.018	1.97
July 7......	Fair	0 51	1.07	188	302	1.31	1.030	2.16
7......	Fair	3 36	1.51	162	303	1.10	1.030	2.11
Aug. 24......	Good	1 17	1.18	210	348	1.14	1.023	1.93
24......	Good	1 47	1.24	202	345	1.12	1.023	1.95
Oct. 14......	Good	1 58	1.72	250	408	1.23	0.990	1.98
14......	Good	2 25	1.88	246	408	1.18	0.990	1.94
29......	Good	0 59	1.69	233	415	1.13	0.981	1.97
Dec. 7......	Good	2 45	3.34	221	479	0.92	0.970	1.94
23......	Good	1 39	2.52	242	423	1.16	0.970	1.96
23......	Good	2 41	3.38	205	418	1.02	0.970	2.01
1904, Jan. 27......	Fair	1 49	2.20	205	369	1.18	0.970	2.05
27......	Fair	2 55	2.98	169	350	0.99	0.970	1.98
Feb. 11......	Fair	1 19	1.81	187	374	1.18	0.972	2.29
11......	Fair	2 29	2.27	168	381	1.02	0.972	2.24

III. POSSIBILITY OF CONSIDERABLE CHANGES IN THE AMOUNT OF SOLAR RADIATION OUTSIDE THE ATMOSPHERE.

Looking at the general results, these seem then to indicate a possibility that a rapid fall of solar radiation occurred about the close of March,[2] and that subsequently the radiation continued

[1] This day has been called "excellent," though in computations of the area of the energy-curve outside the atmosphere there is a larger difference than usual. But this is immediately explainable, if, as appears, the solar radiation itself was rapidly diminishing at the time; for this would result in too small apparent transmission coefficients, so that the second area computed would be larger than the first.

[2] It is of interest to note that a marked increase of Sun spots occurred on March 21. See Report of the Council, *Monthly Notices* of the Royal Astronomical Society, **64**, 357.

nearly or quite 10 per cent. less than before. This, if certain, would be important, and we may inquire what causes on the Sun could produce such a change, and what effects might be expected to be produced on the Earth if it occurred.

The writer showed nearly thirty years ago[1] that the envelope of the Sun profoundly influences by its absorption the radiation received by the Earth. While the absorption in the solar envelope is not exactly known, still so much is known that we may infer that if it were absent for a moment the Earth would receive nearly double its present amount of heat. If a variation of 10 per cent. in the transparency of this envelope occurred, nearly 10 per cent. of change in the solar radiation outside the Earth's atmosphere would follow.

If a fall of solar radiation did occur, there ought to have been a similar change of terrestrial temperatures afterward, and we may inquire how great this fall of temperature should be.

The Earth may be regarded as a body at a mean temperature of 290° absolute (17° C.), maintained at approximately constant temperature by a balance between solar radiation received and terrestrial radiation emitted. It is here assumed that all sources of heat other than the solar radiation are negligible, but if any or all of them are not so, the effect of their presence will be to reduce the effect on temperature of a fall in solar radiation.

Recent studies of German physicists have experimentally verified, for the perfect radiator, Stefan's law that the emission of a heated body is proportional to the fourth power of the temperature.[2] Other bodies not perfect radiators depart from this law in the sense that, while radiating less absolutely than the perfect radiator, their emission is more nearly proportional to a power of the temperature higher than the fourth.[3] Suppose T_1 to be the mean temperature of the Earth corresponding to a rate of solar radiation S_1, and T_2 that corresponding to S_2. Assume further that the reflecting power of the Earth remains

[1] *Comptes Rendus*, **81**, 436, Sept. 6, 1875.

[2] O. LUMMER, *Rapports présentés au Congrès International de Physique*, **2**, 78–81, 1900.

[3] H. KAYSER, *Handbuch der Spectroscopie*, **2**, 77–82.

unchanged, and that no appreciable heat is received from other sources than the Sun. Then

$$\left(\frac{T_2}{T_1}\right)^x = \frac{S_2}{S_1}, \quad \text{where } x > 4 .$$

Accordingly if, as supposed, S_2 is $9/10\ S_1$,

$$T_2 > 0.974\,T_1 .$$

If $T_1 = 290°$, then $T_2 > 282°.5$, and $T_1 - T_2 < 7°.5$ C.

It may then be stated that if the solar radiation remained for a long period of time at a value which would maintain the Earth's surface at a mean temperature of 17° C., and then fell 10 per cent., and so remained indefinitely, the fall of temperature of the Earth's surface would be less than 7°.5 C.

But if the solar radiation fluctuated between limits separated by 10 per cent., the fluctuation of terrestrial temperature would be less, according to the frequency of the fluctuations of solar radiation. Again, parts of the Earth's surface most closely associated with the oceans by the influences of winds, ocean currents, and rainfall would be least affected by such solar fluctuations, and would respond most slowly to a permanent alteration of solar radiation.

From the foregoing considerations we may then infer that the effect of a fall of 10 per cent. in the solar radiation should diminish the mean temperature of the Earth not more than 7°.5 C., and indefinitely less according to the shortness of the time elapsing before the radiation regained its former value. Stations near the sea, or subject to ocean currents and winds, or to heavy rainfall, would lag far behind stations in the interior of great continents in their temperature fluctuations.

When we come to the study of actual temperatures over the Earth's surface, we find that all collections of temperature data for single stations in the interior of great continents, covering long periods of time, exhibit nearly every year such considerable irregular variations from the normal temperatures that we are at no loss to find variations comparable in dimensions with those we are supposing to be caused by a fluctuating solar radiation. But it is only within the last year that we have the series of

radiation measures with which to compare temperatures, and we now turn to recent temperatures as published in the *Internationaler Dekadenberichte* of the *Deutsche Seewarte* for nearly one hundred stations, for each ten-day period of 1903, and accompanied by normal temperatures representing the mean for the same ten-day periods of many former years.[1] From all the stations for which normal values are given, temperature departures have been computed here, and these departures have been averaged by geographical position in seven groups, comprising (1) North America, 20 stations; (2) Insular and Southwest Europe and North Africa, 18 stations; (3) Northwest Europe, 15 stations; (4) Central Europe, 10 stations; (5) European Russia, 11 stations; (6) Asiatic Russia, 8 stations; (7) High Altitudes in Europe, 7 stations. These seven groups of results are plotted in the accompanying chart (in which, to avoid confusion, the lines are alternately continuous and dotted), and as all seem to show the same tendency in more or less marked degree, no hesitation was felt in taking the general mean, giving observations of each station equal weight wherever present in the sum. The general mean for the 89 stations forms the (heavy) eighth line of the chart, and a comparison is invited between its course and that of the ninth and lowest line representing the observations of solar radiation made during 1903 at Washington.[2] In connection with this comparison the reader is reminded that during September an increasing transparency of the atmosphere was noted, which may have had the direct effect, discussed on a former page, of increasing terrestrial temperatures thereafter, and thus accounting for the observed rise of the mean temperature at the close of the year. If this be admitted, the general agreement of the observed temperatures with what radiation measures would lead us to expect, is certainly marked.

As for the total fall of temperature indicated by the charts,

[1] The writer is indebted to Professor Cleveland Abbe and to Dr. W. F. R. Phillips, librarian of the U. S. Weather Bureau, for their aid in making accessible the publications of temperature data in possession of the Weather Bureau.

[2] It is to be regretted that only one day of observation, with at all satisfactory conditions, was secured between April 29 and August 24, and that (July 7) of less weight than the others.

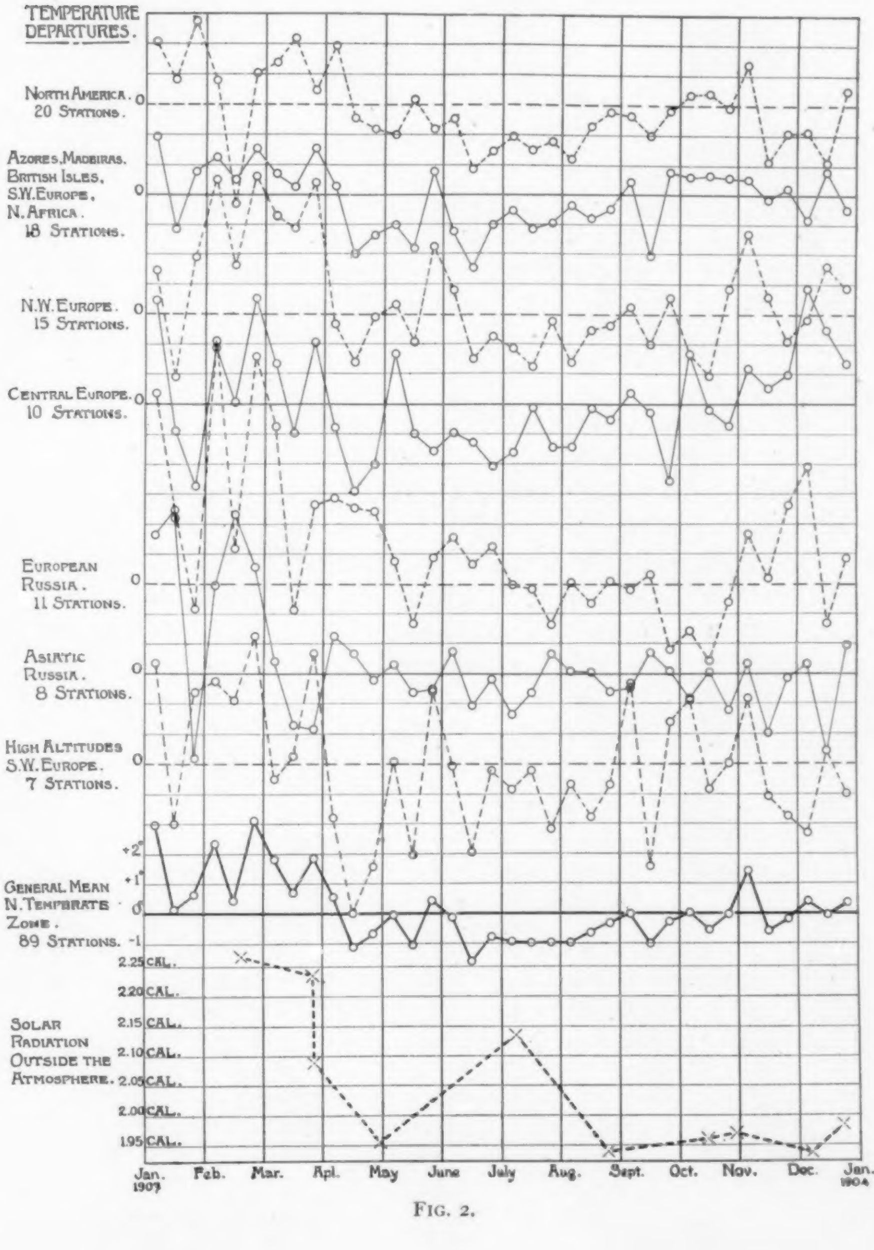

TEMPERATURE DEPARTURES.
NORTH AMERICA. 20 STATIONS.
AZORES, MADEIRAS, BRITISH ISLES, S.W. EUROPE, N. AFRICA. 18 STATIONS.
N.W. EUROPE. 15 STATIONS.
CENTRAL EUROPE. 10 STATIONS.
EUROPEAN RUSSIA. 11 STATIONS.
ASIATIC RUSSIA. 8 STATIONS.
HIGH ALTITUDES S.W. EUROPE. 7 STATIONS.
GENERAL MEAN N. TEMPERATE ZONE. 89 STATIONS.
+2°
+1°
0°
-1
SOLAR RADIATION OUTSIDE THE ATMOSPHERE.
2.25 CAL.
2.20 CAL.
2.15 CAL.
2.10 CAL.
2.05 CAL.
2.00 CAL.
1.95 CAL.
Jan. 1903
Feb.
Mar.
Apl.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Jan. 1904

FIG. 2.

that is seen to be a maximum for European and Asiatic Russia, the regions most removed from the influences of the oceans. The fall in the general mean for the land areas of the North Temperate zone[1] is, however, over 2° C., or about one-third of the maximum fall possible to be caused by a permanent diminution of solar radiation of 10 per cent. It is the absorption of heat by the oceans which retards the terrestrial change (if any) produced by change in the solar constant. Since the indirect effects of the absorption of solar radiation are felt in the oceans to depths of 2,000 meters, it may be shown that a change of 2° C. over the entire surface of the Earth would be delayed over a year.

SUMMARY AND CONCLUSION.

A series of determinations of the solar radiation outside the atmosphere (the solar constant)[2], extending from October 1902 to March 1904, has been made at the Smithsonian Astrophysical Observatory under the writer's direction.

Care has been exercised to determine all known sources of error which could seriously affect the values relatively to each other, and principally the varying absorption of the Earth's atmosphere. Though uncertainty must ever remain as to the absorption of this atmosphere, different kinds of evidence agree in supporting the accuracy of the estimates made of it and of the conclusions deduced from them.

The effects due to this absorption having been allowed for, the inference from these observations appears to be that the solar radiation itself fell off by about 10 per cent., beginning at the close of March 1903. I do not assert this without qualification, but if such a change in solar radiation did actually occur, a decrease of temperature on the Earth, which might be indefinitely less than 7°.5 C., ought to have followed it.

[1] It would be of great interest to extend the discussion of temperature departures to include stations in the interior of South America, Africa, Australia, and southern Asia, but the data are not now available, and for many regions of these continents may long be wanting.

[2] I wish to renew my caution that the *absolute* values of the solar constant thus given are more likely to be found in defect than in excess.

On comparing the observed temperatures of 89 stations, distributed over the North Temperate Zone, with the mean temperatures of the same stations for many previous years, it is found that an average decrease of temperature of over 2° C. actually did follow the possible fall of the solar radiation, while the temperature continued low during the remainder of the year. Stations remote from the retarding influence of the oceans show a much greater variation than that of the general mean.

While it is difficult to conceive what influence, not solar, could have produced this rapid and *simultaneous* reduction of temperatures over the whole North Temperate Zone, and continued operative for so long a period, the evidence of solar variation cannot be said to be conclusive. Nevertheless, such a conclusion seems not an unreasonable inference from the data now at hand, and a continuation of these bolographic studies of solar radiation is of increasing interest, in view of their possible aid in forecasting terrestrial climatic changes, conceivably due to solar ones.

All the preceding observations, while under my general direction, have been conducted in detail by Mr. Abbot, to whom my thanks are especially due.

WASHINGTON, April 15, 1904.

A STUDY OF ENHANCED LINES OF TITANIUM, IRON, AND NICKEL.

By HERBERT M. REESE.

IN this investigation the enhanced lines in the spectra of titanium, iron and nickel were studied in the region from λ 4200 to λ 5000. In brief, the method consisted in photographing the arc spectrum and the spark spectrum of the same metal and noting those lines which were distinctly brighter in the spark than in the arc.

It is necessary to bear in mind, in discussing the subject of enhanced lines, that the arc and spark are perfectly independent sources, so that the relative duration of the two exposures determines whether every line in the spark shall be stronger than the line of identical wave-length in the arc, or just the reverse, or whether any intermediate condition shall exist. The only fixed data are the ratios of intensity of the arc lines among themselves and the corresponding ratios for the spark lines. Hence, if we fix the exposure times so that any line A has the same intensity in the photographs of arc and spark, any other line B may be regarded as enhanced if the ratio of its intensity to that of A is greater in the spark than in the arc, "depreciated" (if one may, in the emergency, apply such a meaning to this word) if this ratio is less in the spark than in the arc. Strictly speaking, the choice of the line A is arbitrary, but the classification of lines into those that are enhanced and those that are not enhanced acquires a physical significance when quite a number of the lines, say half the total number, or more, can at once be made of about equal intensity in the two spectra. This is generally the case, at least with spectra such as those of iron and titanium, which contain very many lines.

In order to facilitate the comparison, the camera of the ten-foot concave grating of the spectroscopic laboratory of the Yerkes Observatory was arranged so that several different exposures could be made upon the same plate. Several expos-

ures of varying duration were made in the second-order spectrum with the spark as source of light; then, on the same or a different plate, several exposures of varying duration with the arc as source. After developing, etc., one spark exposure and one arc exposure were chosen such that the majority of the lines were of about the same intensity in the two. The plate was then carefully examined, and all lines were marked which were appreciably stronger or weaker in the spark than in the arc. The plate was then measured, in sections one-third of the total length, upon a Zeiss comparator. The measurements were made upon the spark spectrum; and, besides the lines previously marked, many other good lines were measured, partly to serve as standards for determining the wave-lengths of others, partly to be given as examples of the lines which are made of equal intensity in spark and arc. The plates were measured both with violet to left and with violet to right. In some cases eight settings in all were made upon a single line, in most cases only four. The wave-lengths were determined from the measurements in the usual way. Two lines of known wave-length (taken from Rowland's *Preliminary Table of Solar Spectrum Wave-Lengths*) were taken as standards, and the wave-lengths of the others determined by linear interpolation on the assumption that the spectrum was strictly normal. Then for such of these as were also given in Rowland's table, the residuals were plotted; and an error curve was drawn, by means of which all the wave-lengths obtained by interpolation were corrected. An idea of the degree of accuracy obtained may be gotten from a consideration of the final residuals in the case of those lines that are given in Rowland's table. The probable error determined from these lines in the cases of iron and titanium is ± 0.008 tenth-meter for the determination of a single line. In the case of nickel the lines were less sharp and the continuous spectrum much stronger, so that the probable error is greater, viz., ± 0.013 tenth-meter. In all cases, however, many lines were included which were difficult to measure, because of either extreme faintness or great breadth, so that the accuracy of measurement for good lines was greater than these figures would indicate.

In all cases the spectra showed some impurities, but so far as possible all lines not due to the element being studied were eliminated by a comparison with well-known tables of the wave-lengths of elements.

The current for generating the spark was supplied from a transformer wound in the ratio of 110 to 15,000. The current in the primary was about 19 amperes and the potential-difference about fifteen volts. In parallel with the secondary was a condenser of 0.0255 microfarads capacity. No self-induction was inserted in the spark circuit. The spark was passed between pieces of the metal under investigation about 3 mm apart. For iron and nickel cylindrical pieces of the metal were used, two or three millimeters in diameter; for titanium, pieces of irregular shape.

To obtain the arc spectrum, ordinary carbon poles were used, with pieces of the metal inserted in a hole in the lower carbon.

In the tables are given all lines which are regarded as enhanced or the reverse, all those which were used as standards for the determination of wave-lengths, and some others not included in either of the above categories, but inserted as examples of the lines regarded as unaffected in passing from arc to spark. Among the lines used as standards for wave-length are a number due to impurities.

The wave-length of the line as measured on my plates is given in the first column; the corresponding wave-length in the Sun, from Rowland's *Preliminary Table of Solar Spectrum Wave-Lengths*, is given in the second, if the line happens to be one of those used as standards for determining wave-lengths. The third and fourth columns give the intensities in spark and arc respectively. In the fifth are Lockyer's[1] wave-lengths of enhanced lines; while the sixth is devoted to general remarks.

A very strong line is designated by the intensity 10 or 9, while 1 denotes a very faint one. A line so faint as to be measured with great difficulty is denoted by the abbreviation "tr." or "trace." The letter "m." signifies that the line is missing.

[1] *Proc. R. S.*, **65**, 452, 1899.

TITANIUM.

Pieces of the metal obtained from the electric furnace of Professor Moissan were used. It showed traces of vanadium, but no other impurities were detected with certainty.

Wave-Length	Rowland	Int. in Spark	Int. in Arc	Lockyer	Remarks
4224.87		3	3		
27.43		2–3	1–2	27.40	
38.00		4	4		
45.64		3	3		
48.39		2	tr.?		Not identified.
49.27	49.27	3	3		
52.20		2	tr.		Not identified.
63.28	63.29	4	4		
71.91		2–1	tr.?		Not identified.
72.10		2	tr.		Not identified.
87.57	87.57	4	4		
88.04	88.04	3	2		
90.41	90.38	6	4	90.38	
93.39		2	1		Not identified.
93.68		2–1	tr.		Not identified.
94.28		6	4	94.20	
95.90	95.91	4	4		
4300.21	00.21	7	3	00.21	
02.10	02.08	5	3		
03.19		4	3		Not identified.
05.07		3	2		Not identified.
06.06	06.08	7	7		
08.05		6	4		
				08.60	
10.02		2–3	2		Not identified.
11.04		2–3	1–2		Not identified.
13.06	13.03	6	4	13.03	
14.93	14.96	4	4		
15.18		5	3	15.14	
16.95	16.96	3	2	16.96	
18.81		4	4		
21.12		4	2–3	21.20	
25.31	25.31	4	4		
30.41		4	2	30.50	
30.86	30.87	4	2–3	30.87	
35.01		3	3		
37.56		2–3	tr.		
38.06	38.08	6–7	5	38.08	
38.64		1–2	3		
41.52	41.53	4	3	41.53	
44.44	44.45	4	3	44.45	
51.00	51.00	4	2	51.00	
60.65	60.64	3	3		
64.78		2	m.		Not identified.
67.83	67.84	6	3	67.84	
70.86		2	m.		Not identified.
72.54		3	3		
74.99		4	2	74.90	

TITANIUM—*Continued.*

Wave-Length	Rowland	Int. in Spark	Int. in Arc	Lockyer	Remarks
4382.99		1	tr.		Not identified.
83.71		2	1		Not identified. *Fe* 4383.72 ?
83.98		1	tr.		Not identified.
87.03	87.01	6	2	87.01	
91.19	91.19	3	2	91.19	
95.19	95.20	9	5	95.20	
96.00	96.01	3	2	96.01	
96.87		2-1	1		Not identified.
98.24		2-3	2		
98.45		2	1		
99.94	99.94	6	4	99.94	
4402.99		2	1		Not identified.
07.83	07.82	3	3		*V* Standard.
08.36		1-2	2		
08.67		2	3		
09.40		2-3	1		
09.68		2-3	1-2		
11.23	11.24	6	2	11.20	
12.09		2-3	1		
16.70		3	3		
17.90	17.88	5	3	17.88	
18.50	18.50	4	3		
22.10		3	1	21.93	
31.44		3	3		
32.27		2	tr.		
40.88		2	1		Not certainly identified as *Ti*.
41.89		3	2		
43.94	43.98	9	5	43.98	
44.72	44.73	3	2		
50.64	50.65	4	3	50.65	
56.81		2	m.		
64.62	64.62	4	3	64.62	
65.97	65.98	4	4		
68.66	68.66	9	5	68.66	
71.02	71.02	3	2		
80.75	80.75	3	3		
88.49		6	3	88.49	
95.17	95.18	3	3		
4501.45	01.45	9	5	01.45	
04.59		2-3	1-2		Not identified.
11.33		3	3		
22.98	22.97	5	5		
29.67		4	2	29.60	
34.15	34.14	7	4	34.14	
37.35		4	3		
44.18		3	2		
44.87	44.86	4	4		
46.66		4	2		Not iden. Weak *V* line at 46.57.
48.94	48.94	4	5		
49.83	49.81	9	5	49.81	
60.09	60.10	3	3		
63.94	63.94	7	5	63.94	
67.12		3	1		Not identified.

TITANIUM—*Continued.*

Wave-Length	Rowland	Int. in Spark	Int. in Arc	Lockyer	Remarks
4568.49		2-3	1		
69.00		4	2		Not identified.
72.17	72.16	9	5	72.16	
75.34		4	2		Not identified.
80.60	80.59	2	1		*V* Standard.
83.59		2	1		
90.14		5	3	90.13	
4609 55		4	3		
17.45	17.45	5	5		
29.52	29.52	4	4		
38.05	38.05	3	3		
50.20	50.19	4	4		
57.37	57.38	3	1		
87.98		2	1		
91.52	91.52	5	5		
93.85	93.85	2	2		
4708.85		2-3	1		Not identified.
10.38	10.37	5	5		
22.80	22.80	3	3		
23.35	23.36	3	3		
58.31	58.31	5	5		
62.97		1-2	1		Not identified.
64.08	64.11	4	2		
64.72		2-3	1-2		Not identified.
78.44	78.44	4	4		
80.16		5	3		Not identified.
96.40	96.37	3	3		
98.57		2	1		Not identified.
99.98	99.98	4	4		
4805.26		4	2		
12.42	12.43	2	2		
20.60	20.59	5	5		
36.31	36.31	2	2		
56.20		5	5		
65.82		2	1		Not identified.
68.44	68.45	5	5		
74.18		4	1		Not identified.
85.27	85.26	5	5		
92.58		3	m.		Not identified.
4900.10	00.10	5	5		
08.30		1	m.		Not identified.
11.39		5	1		
13.80	13.80	5	5		
17.62		2-3	tr.?		Not identified.
18.55		2-3	tr.?		Not identified.
23.68		2	1		Not identified.
28.52	28.51	4	4		
32.84		1	m.		Not identified.
33.04		1	m.		Not identified.
38.47		3	3		
63.41		2	1		Not identified.
75.52	75.53	3	3		
77.25		2-3	1		Not identified.

TITANIUM—*Continued.*

Wave-Length	Rowland	Int. in Spark	Int. in Arc	Lockyer	Remarks
4981.92	81.91	6	6		
82.72		3	1		Not identified.
84.58		4	1		Not identified.
89.34	89.33	4	4		
90.38		3	1		Not identified.
97.28	97.28	3	3		
98.33		4	1		Not identified.
5009.83	09.83	2	2		

It will be seen that this list includes all the enhanced lines given by Lockyer within this region, with the possible exception of the line at λ 4308.60, which is probably the same as my line at λ 4308.05, notwithstanding the great discrepancy in wave-length. It may be noted that Hasselberg gives an arc line at λ 4308.64, while Exner and Haschek give, for the spark, in addition to a weak line at λ 4308.67, a strong one at λ 4308.08. I carefully remeasured this line both in the spark and in the arc, and obtained the same value, λ 4308.05, in both cases. It is not likely that the iron line λ 4308.08 comes in here as an impurity, since the only other iron line suspected of being present is λ 4383.73, and this is much fainter.

Besides the lines noted by Lockyer, the table gives as enhanced the following lines, which have been identified as belonging to titanium, according to the tables of Hasselberg for the arc, or of Exner and Haschek for the spark:

4228.04	4409.40	4440.88	4537.35	4657.37
4305.07	09.68	41.89	44.18	87.98
37.56	12.09	44.72	68.49	4764.08
98.24	18.50	56.81	83.59	4805.26
98.45	32.27	71.02	4609.55	4911.39

The enhanced lines in the following list have not been identified in any other list of titanium lines, but may at least provisionally be ascribed to that metal:

4248.39	4311.04	4504.59	4798.57	4932.84
52.20	64.78	46.66	4865.82	33.04
71.91	70.86	67.12	74.18	63.41
72.10	82.99	69.00	92.58	77.25
93.39	83.71	75.34	4908.30	82.72
93.68	83.98	4708.85	17.62	84.58
4303.19	96.87	62.97	18.55	90.38
05.07	4402.99	64.72	23.68	98.33
10.02	40.88	80.16		

The following lines, instead of being enhanced, are diminished in brightness on passing from the arc to the spark:

4338.64 4408.36 4408.67

IRON.

The only impurities detected were manganese and calcium. Many of the standard lines are omitted.

Wave-Length	Rowland	Int. in Spark	Int. in Arc	Lockyer	Remarks
4219.52	19.52	3-4	3		
20.50	20.51	1	tr.		
22.38	22.38	3	3		
25.63	25.62	2	2		
26.11	26.12	1	tr.		
26.58	26.58	1	tr.		
27.61	27.61	4	4		
29.69	29.68	tr.	m.		
30.54		tr.	m.		
30.86		tr.	m.		
33.17		1	m.		Not identified.
33.34	33.33	2	m.	33.25	
36.11	36.11	4	4		
38.99	38.97	2	2		
39.90	39.89	1	1		*Mn* standard.
40.53	40.54	1	m.		
42.89	42.90	tr.	m.		
46.24	46.25	1	m.		
47.98		1	tr.		Not identified.
50.29	50.29	5	5		
50.96	50.94	6	5		
53.73		tr.	m.		Not identified.
53.90		1	m.		
54.50	54.50	tr.	1		
60.65	60.64	6	6		
63.60		1	tr.		Not identified.
67.11	67.12	1	1		
68.36		1	tr.		Not identified.
68.94	68.92	3	tr.		
71.33	71.32	5	5		

IRON—*Continued.*

Wave-Length	Rowland	Int. in Spark	Int. in Arc	Lockyer	Remarks
4271.94	71.93	7	6		
74.90		2	1		
77.88		1	m.		
79.60	79.59	tr.	m.		
82.56	82.56	4	4		
85.59	85.60	1–2	1		
87.69		1	m.		Not identified.
88.32		tr.	m.		
90.50	90.54	tr.	m.		
94.29	94.30	5	5		
96.08		tr.	m.		
96.74		tr.	m.	96.65	
97.26		1	m.		Not identified.
98.21	98.20	2	1		
99.41	99.41	5	5		
4303.34		1	m.		
05.08		2–3	m.		Not identified.
07.53		1	m.		
08.08	08.08	8	7		
09.20	09.20	1	tr.		
09.55	09.54	2	2		
10.28		tr.	m.		
11.07		2–3	tr.		
15.25	15.26	3	3		
22.92		3	tr.		
25.95	25.94	8	7		
28.95		2	tr.		
31.96		1	m.		
36.92		tr.	m.		Not identified.
37.22	37.22	3	3		
43.45	43.43	tr.	m.		
43.89	43.86	tr.	m.		
46.73	46.72	tr.	m.		
51.94	51.95	2	m.	51.93	
52.91	52.91	3	3		
67.75	67.75	2	1–2		
71.52		1	tr.		
73.75	73.73	tr.	m.		
76.10	76.11	3	3		
80.67		3	tr.		
83.73	83.72	10	9		
85.55		1	m.	85.55	
86.77		3	tr.		
88.06	88.06	1	tr.		
88.58	88.57	1–2	1		
89.81		tr.	m.		Not identified.
90.05		tr.	m.		
91.12	91.12	1	tr.		
92.68		tr.	m.		
92.84		tr.	m.		Not identified.
4401.46	01.46	1	tr.		
01.86		2	tr.		Not identified.

IRON—*Continued.*

Wave-Length	Rowland	Int. in Spark	Int. in Arc	Lockyer	Remarks
4404.93	04.93	9	7–8		
07.99		2–3	m.		
08.59	08.58	2	2		
12.22		2	tr.		
15.32	15.29	7	6–7		
18.36		2	m.		
21.69		1	m.		Not identified.
21.99		tr.	m.		Not identified.
22.74	22.74	2	2		
23.98	24.01	1	m.		
27.48	27.48	3	3		
33.38	33.39	2	1		
42.51	42.51	3	3		
47.89	47.89	3	3		
50.51	50.48	1	m.		
59.30	59.30	3	3		
61.82	61.82	2	2		
66.72	66.73	4	3–4		
69.56	69.54	2	2		
76.19	76.18	3	3		
77.43		1	m.		
89.38		tr.	m.	89.35	Not identified.
89.90	89.91	1	1		
91.58		1	m.	91.57	
94.74	94.74	3	3		
4504.17		tr.	m.		Not identified.
08.46	08.46	1–2	m.	08.46	
15.51		1	m.	15.51	
20.39	20.40	1	m.	20.40	
22.81		2	m.	22.69	
25.66		tr.	m.		Not identified.
28.80	28.80	4	4		
31.32	31.33	2	2		
31.88		1	m.		Not identified, hazy.
48.02	48.02	1–2	1		
49.66	49.64	2–3	m.	49.64	
56.07		1	m.	56.10	
56.30	56.31	1	1		
76.51		tr.	m.	76.51	Not identified.
84.02	84.02	3	m.	84.02	
98.30	98.30	tr.	m.		
4603.12	03.13	2	2		
19.46	19.47	1	tr.		
29.50		1	m.	29.60	
37.69	37.68	1	tr.		
38.21	38.19	1	tr.		
47.62	47.62	2	2		
69.34	69.35	tr.	m.		
73.36	73.35	tr.	m.		
91.59	91.60	1	tr.		
4710.46	10.47	1	tr.		
54.23	54.23	1	2		*Mn* standard.

IRON—*Continued.*

Wave-Length	Rowland	Int. in Spark	Int. in Arc	Lockyer	Remarks
4783.62	83.61	1	2		*Mn* standard.
86.99		1	tr.?		
89.83	89.85	1-2	tr.		
4823.69		1	2		
71.50	71.51	3	3		
90.94	90.95	3	3		
91.68	91.68	4	4		
4924.11	24.11	3	m.	24.11	
97.99		tr.	m.		Not identified.
5002.05		2	1		
05.90	05.90	2	tr.		
06.31	06.31	2	1-2		

Lockyer gives five enhanced lines in this region of the iron spectrum which are not included in the above table. These are λλ4302.35, 4451.75, 4462.30, 4541.40, and 4635.40. For the first line Lockyer gives the intensities 2-3 in the spark and 2 in the arc. On my plates it appears a trifle stronger in the spark than in the arc, but so little that I hardly felt justified in classifying it with the enhanced lines. The line 4451.75 is not enhanced on my plates, nor is the line 4462.18, which is probably the same as Lockyer's λ4462.30. My plates do not show λ4541.40 nor λ4635.40.

The table gives the following enhanced lines not given by Lockyer, but all identified as iron lines:

4219.52	4274.90	4322.92	4388.58	4477.43
20.50	77.88	25.95	90.05	4548.02
26.11	79.60	28.95	91.12	98.30
26.58	85.59	31.96	92.68	4619.46
29.69	88.32	43.45	4401.46	37.69
30.54	90.50	43.89	04.93	38.21
30.86	96.08	46.73	07.99	69.34
40.53	98.21	67.75	12.22	73.36
42.89	4303.34	71.52	15.32	91.59
46.24	07.53	73.75	18.36	4786.99
50.96	08.08	80.67	23.98	89.83
53.90	09.20	83.73	33.38	5002.05
68.94	10.28	86.77	50.51	05.90
71.94	11.07	88.06	66.72	06.31

Many of these are mere traces and are added only for the sake of completeness.

The following lines are also enhanced, but have not been identified in any lists of iron lines:

4233.17	4268.36	4336.92	4421.69	4531.88
47.98	87.69	89.81	21.99	76.51
53.73	97.26	92.84	4504.17	4997.99
63.60	4303.34	4401.86	25.66	

The only line stronger in the arc than in the spark is λ4823.69.

NICKEL.

The metal used proved to contain traces of iron, manganese, and cobalt, but no other impurities were detected. Lockyer did not investigate this metal.

Wave-Length	Rowland	Int. in Spark	Int. in Arc	Remarks
4231.22	31.18	2–3	2	
32.14		tr.	m.	Not identified.
35.45	35.45	2	m.	*Mn* standard.
36.12	36.11	1	1	*Fe* standard.
44.94	44.96	2	m.	
50.28	50.29	1	1	*Fe* standard.
58.97		2–3	m.	Not identified.
60.63	60.64	2	2	*Fe* standard.
63.36		1–2	m.	Not identified.
71.33	71.32	1	1	*Fe* standard.
71.91	71.93	2	2	*Fe* standard.
79.36		4	m.	
84.85	84.84	3	3	
88.18	88.15	4	4	
91.19		tr.	m.	Not identified.
94.28	94.30	1	1	*Fe* standard.
97.15		1	m.	
98.70	98.68	1–2	1	
4307.45		1–2	1	
08.07	08.08	2	2	*Fe* standard.
25.93	25.94	2	2	
30.92	30.87	1	1	
31.81	31.81	3	3	
56.10	56.16	2	2	
59.76	59.65	3	3	
62.28		4	m.	
68.49	68.46	2	1–2	
70.22	70.19	1	1	
70.57		1–2	m.	Not identified.

NICKEL—*Continued.*

Wave-Length	Rowland	Int. in Spark	Int. in Arc	Remarks
4383.71	83.72	3	4	*Fe* standard.
98.66		2	1–2	
99.80	99.78	1–2	1–2	
4401.09	01.02	2	2	
01.73	01.71	6	6	
04.92	04.93	2	2–3	*Fe* standard.
10.66	10.68	1–2	2	
15.06	15.05	4	m.	*Mn* standard.
15.28	15.29	2	2	*Fe* standard.
23.20		1–2	1	
24.00	24.01	1	m.	*Fe* standard.
37.15	37.11	2	2	
51.74	51.75	1–2	m.	*Mn* standard.
59.21	59.20	6	6	
62.62	62.62	3	3	
63.58	63.57	1	1	
66.60	66.55	2	2	
70.64	70.65	4	4	
72.64		1	m.	Not identified.
80.76	80.75	1	1	
90.70	90.70	1	1	
4503.96		1	m.	Not identified.
05.62		1	m.	Not identified.
09.42		3	m.	
13.17	13.16	2	2	
20.15	20.16	1	1	
24.92		3	m.	Not identified.
31.13	31.12	1–2	1	*Co* standard.
32.48	-	tr.	m.	Not identified.
47.11	47.10	3	3	
47.40	47.40	2	2	
51.41	51.40	2	2	
53.32	53.35	1	2	
60.10	60.10	1	1	
76.48		tr.	m.	Not identified,
80.79	80.76	1	1	
85.85		2–3	m.	Not identified.
92.71	92.71	4	4	
4600.54	00.54	3	3	
05.18	05.17	4	4	
06.39	06.40	2	2–3	
08.38		1	tr.	Not identified.
48.84	48.84	5	6	
65.72		3	m.	Not identified.
67.17	67.16	2	2	
67.94	67.94	2	2	
79.31		4	m.	Not identified.
86.40	86.40	4	4	
4701.73	01.71	3	3	
03.96	03.99	3	3	
12.25	12.26	1	1	
14.61	14.60	6	6	

NICKEL—*Continued.*

Wave-Length	Rowland	Int. in Spark	Int. in Arc	Remarks
4715.93	15.95	3	3	
32.65	32.64	2	2	
52.26	52.29	1	1	
52.58	52.61	2	2	
54.22	54.22	1	m.	*Mn* standard.
54.96	54.95	2	2	
56.71	56.70	4	4	
62.54	62.57	1	m.	*Mn* standard.
62.80	62.82	2	2–3	
64.13	64.11	3	3	
66.63	66.62	tr.	m.	*Mn* standard.
86.45	86.47	1	1	
86.73	86.73	4	4	
4807.18	07.19	3	3	
12.17	12.18	1	1	
18.05	18.00	1	1	
23.71	23.70	1	tr.	*Mn* standard.
29.22	29.21	3–4	4	
31.38	31.36	3	3	
38.86	38.84	2	2	
52.75		1	2	
55.59	55.60	4	4	
57.58	57.58	2	2	
66.46	66.46	4	4	
71.01	71.00	1–2	2	
73.63	73.63	3	3	
75.00	74.98	1	1	
75.99		1	m.	Not identified.
87.18	87.19	1	1	
4904.58		4	4–5	
12.21	12.20	1–2	2	
14.14		1–2	2	
18.55	18.54	3	3	
18.89	18.89	1	1	
25.74	25.75	1–2	1–2	
36.01	36.02	2	2	
37.48	37.52	1	2	
53.40	53.39	1–2	1–2	
71.50	71.53	1	1–2	
73.68		1–2	1	Not identified.
80.33	80.35	3–4	4	
80.55		1	1	
83.64		1	1	
84.29	84.30	3–4	3–4	
98.42	98.41	1	1–2	
5000.50	00.53	1–2	2	
12.64	12.62	1–2	1–2	

The enhanced lines in the above table certainly belonging to nickel are:

4231.22	4279.36	4298.70	4362.28	4398.66
44.94	97.15	4307.45	68.49	4509.42

The following have not been identified:

4232.14	4370.57	4524.92	4585.85	4679.31
58.97	4472.64	32.48	4608.38	4775.99
63.36	4503.96	76.48	65.72	4973.68
91.19	05.62			

The following lines are stronger in the arc than in the spark:

4410.66	4684.84	4871.01	4914.14	4998.42
4553.32	4762.82	4904.58	71.50	5000.50
4609.39	4829.22	12.21	80.33	

It is interesting to note that most of these lie in the same part of the spectrum. In no case is the difference in intensity between arc and spark at all great, and we may interpret the facts by saying that for the less refrangible part of the region investigated a better matching of the intensities of the lines would have been obtained by exposing to the spark spectrum a little longer.

A comparison of the above tables with Rowland's table shows a number of lines which seem to have the same wave-length, well within the limits of error, as lines in the solar spectrum which have not been ascribed by him to any element. Omitting all lines with intensity less than 0 in the Sun, the most striking cases are the following.

λ Spark	Int. in Spark	λ (Rowland)	Int. in ⊙	Element	λ Spark	Int. in Spark	λ (Rowland)	Int. in ⊙	Element
4253.90	1	53.888	0	*Fe*	4515.51	1	15.508	3	*Fe*
4303.34	1	03.337	2	*Fe*	22.81	2	22.802	3	*Fe*
10.02	2–3	09.993	0	*Ti*	29.67	4	29.656	1	*Ti*
21.12	4	21.119	2	*Ti*	44.18	3	44.190	1	*Ti*
30.41	4	30.405	1	*Ti*	68.49	2–3	68.499	0	*Ti*
62.28	4	62.262	0	*Ni*	83.59	2	83.587	0	*Ti*
80.67	3	80.655	0	*Fe*	90.14	5	90.126	3	*Ti*
85.55	1	85.548	2	*Fe*	4708.85	2–3	08.846	2	*Ti*
98.45	3	98.460	0	*Ti*	62.97	1–2	62.969	0	*Ti*
4409.40	2–3	09.408	0	*Ti*	64.72	2–3	64.720	0	*Ti*
09.68	2–3	09.683	1	*Ti*	4852.75	1	52.743	2	*Ni*
12.09	2–3	12.092	1	*Ti*	74.18	4	74.196	0	*Ti*
22.10	3	22.104	1	*Ti*	4904.58	4	04.597	3	*Ni*
88.49	6	88.493	1	*Ti*	11.39	5	11.374	1	*Ti*
91.58	1	91.570	2	*Fe*	14.14	1–2	14.150	2	*Ni*

It is not claimed that these are all cases of actual coincidence, though probably most of them are. Before being finally accepted

they should be carefully examined for coincidence by photographing the arc and the solar spectrum in juxtaposition,

This research was undertaken at the suggestion of Mr. E. B. Frost, to whom many thanks are due for interest shown in the work.

YERKES OBSERVATORY,
April 28, 1904.

THE RADIAL VELOCITIES OF THE BRIGHTER STARS IN THE *PLEIADES*.

By WALTER S. ADAMS.

THE only attempt which has hitherto been made to determine either the relative or absolute radial velocities of the stars in the *Pleiades* group is that of Pickering,[1] who used an objective prism, and found that the relative motion of the seven brightest stars is probably less than 30 km a second. The great difficulty in the way of such a determination, and the one which has led to the neglect of these important stars in modern radial velocity work, is the character of their spectra. These are of the advanced helium type, as Miss Clerke well designates them, and it is in this type that the greatest difficulty is found in securing lines upon which accurate measurements can be made; the helium lines having lost the strength and relatively well defined character which they possess in the representative helium stars, while the type is not sufficiently advanced to show, to any measurable extent at least, the metallic lines which are characteristic of the Sirian stars.

It is clear that in dealing with spectra of this nature the best results are to be expected from the use of comparatively low dispersion. The loss of scale in the plates is more than counterbalanced by the superior definition and increase in apparent strength of the lines present, and the gain in the extent of measurable spectrum is of very great importance in the case of spectra in which the lines are so extremely limited in number. An interesting comparison of results in a case of this nature is given by Hartmann[2] for δ *Orionis*, and his conclusions may be applied with still more emphasis to the stars in the *Pleiades*, since the lines present are considerably weaker and more diffuse than in δ *Orionis*. An exception should be made here in the case

[1] ASTROPHYSICAL JOURNAL, 4, 372–3, 1896.

[2] *Sitzungsberichte der Kgl. Akad. der Wissenschaften zu Berlin*, 14, 14, 1904.

of *Maia* (20 *Tauri*), the spectrum of which can be studied to advantage with high dispersion. Reference will be made later to the characteristic features of its spectrum.

All of the plates used in this investigation, with two exceptions, were obtained with the Bruce spectrograph modified for use with one prism, a form in which it has been employed for a large part of the radial velocity work during the past year. The remaining two plates, both of *Maia*, were obtained with the regular three-prism train. The scale of the low-dispersion plates for the position of minimum deviation at $\lambda 4480$ is 1 mm = 30 tenth-meters, and the extent of spectrum within which measures have been made is from the helium line at $\lambda 4026$ to $H\beta$ at $\lambda 4862$.

Six stars are included in this discussion, for all of which at least three plates have been obtained. It was originally intended to include *Pleione* and *Celaeno* as well, but unfortunately the lack of suitable observing weather has made this impossible. The remarkable character of the spectrum of *Pleione* would make the investigation of this star of particular interest.

In view of the extreme difficulty of the measures involved, it has seemed best to repeat so far as possible, and accordingly duplicate measurements have been made throughout. Every effort has been used to keep these entirely independent: the second measurement has always been at a considerable interval after the first so that there might be no tendency on the part of the observer unconsciously to carry in his mind any recollection of the estimated positions of the lines involved. This is a matter of considerable importance in the case of such spectra as those of the *Pleiades*, since the excessively broad and ill-defined character of the lines occasionally gives rise to an option in the estimated position of a line, and complete independence of judgment in such a case is essential to guard against systematic error.

The wide range in the quality of the lines measured has made some process of weighting necessary, and accordingly the procedure has been adopted of assigning a weight to each line at the time of measurement, and combining these weights to form

the result given by the plate.[1] In the case of two measurements of the same plate, however, the simple mean of the two results has been taken as the final value. The difference in the number of lines measured in such cases is usually small, and the additional lines included are invariably of low weight, and would affect the result but slightly.

The table which follows gives the results for five of the stars. In addition to the name of each star, Bessel's number is added for convenience in reference. The magnitudes given are those of the *Harvard Photometry*. The velocities are, of course, in all cases referred to the Sun.

Electra (17 *Tauri*); Mag. 3.8.

Plate	Date	First Measure		Second Measure		Mean Velocity
		Velocity	No. of lines	Velocity	No. of lines	
		km		km		km
I B 110	1903, October 10	+16.2	4	+17.5	4	+16.8
165	October 30	11.0	5	15.4	5	13.2
271	1904, January 29	12.7	4	14.4	3	13.5

Mean +15

Taygeta (19 *Tauri*); Mag. 4.4

I B 257	1904, January 23	+4.5	5	+4.1	4	+4.3
295	March 19	3.9	6	1.5	6	2.7
303	April 15	2.6	5	1.8	4	2.2

Mean +3

Merope (23 *Tauri*); Mag. 4.2

I B 234	1903, December 27	+6.0	4	+6.7	5	+6.4
293	1904, March 19	3.9	5	6.0	6	5.0
313	April 16	8.4	4	6.7	4	7.5

Mean +6

Alcyone (25 *Tauri*); Mag. 3.0

I B 164	1903, October 30	+16.4	3	+18.3	4	+17.3
216	December 4	12.3	5	15.5	3	13.9
221	December 25	14.8	4	11.8	5	13.3

Mean +15

[1] See Frost and Adams, "Radial Velocity of Twenty Stars Having Spectra of the *Orion* Type." *Publications of the Yerkes Observatory*, **2**, 151, 1903.

Atlas (27 *Tauri*); Mag. 3.8

I B 163	1903, October 30	+ 15.6	4	+ 12.4	5	+ 14.0
220	December 25	11.5	3	13.3	5	12.4
272	1904, January 29	14.7	4	14.5	3	14.6
282	February 26	9.5	6	9.9	4	9.7

Mean + 13

So far as any estimate can be formed of the degree of accuracy of the above determinations, it is probable that those for *Taygeta* are most accurate, and those for *Merope* least so, with little to choose among the other three stars. The conclusion in regard to *Taygeta* is due to the fact that its spectrum differs sensibly from that of the other stars in the list, the lines being stronger and narrower as well as slightly better defined. None of the plates of *Alcyone* show evidence of the presence of a bright line at $H\beta$.

The observations of *Maia* lead to the interesting conclusion that the velocity of this star is variable. Seven plates have been obtained, as indicated in the list which follows. B 545 and B 552 were taken with a dispersion of three prisms.

Maia (20 *Tauri*); Mag. 4.0.

Plate	Date	First Measure		Second Measure		Mean Velocity
		Velocity	No. of lines	Velocity	No. of lines	
		km		km		km
I B 166	1903, October 30	− 7.0	5	− 7.8	4	− 7.4
219	December 25	+ 21.0	2	+ 20.8	5	+ 20.9
235	December 27	− 6.5	4	− 4.0	5	− 5.2
244	1904, January 2	+ 0.8	7	+ 7.8	4	+ 4.3
B 545	January 9	+ 1.7	6	+ 2.3	7	+ 2.0
I B 294	March 19	+ 10.0	9	+ 7.8	8	+ 8.9
B 552	March 25	+ 2.0	6	+ 1.5	4	+ 1.8

mean + 3.6

23 plates
avell + 9.3

Though the range here indicated is not very large, the character of the spectrum fortunately is such as to make it almost certainly real. The lines without exception are greatly superior to those in the spectra of any of the other stars in the list for purposes of measurement, the hydrogen lines being strong and narrow, and the magnesium line at λ 4481 well defined. The spectrum is, in fact, decidedly at variance with what we should expect

for a star closely involved in nebulosity, and is in marked contrast to that of the similarly situated star *Merope*. This fact, considered in connection with the low absolute velocity which an inspection of the measures indicates with reasonable certainty for the system of *Maia* (assuming its binary character to be proven), may perhaps warrant the suspicion that this star as well as its neighbor *Taygeta*, is not physically connected with the nebulosity. On the other hand, the character of the spectrum of the remaining four stars is precisely of the sort which is encountered among nebulous stars, and would furnish a strong presumption in favor of their connection with the nebulosity in this case. As is well known, the proper motions of all the brighter stars in the *Pleiades* are small. Newcomb[1] finds for *Alcyone* the annual proper motion

$$\Delta\alpha = +0\overset{s}{.}0132\,;\quad \Delta\delta = -0\overset{''}{.}0587;\ \text{in a great circle } 0\overset{''}{.}060;$$

and this motion is found to satisfy the remaining stars within the limits of error of the observations. A similar conclusion is reached by Elkin[2] as to the absence of relative motion among the bright stars of the group. The small value of the radial velocity of *Merope* would seem to argue against its association with *Alcyone*, *Atlas*, and *Electra*, but, in view of the low degree of accuracy attained in its determination, the argument is by no means strong.

The following brief summary of the results for the stars which we have considered here may be of convenience:

Electra	+14 km
Taygeta	+ 3
Maia	Variable
Merope	+ 6
Alcyone	+15
Atlas	+13

In conclusion, emphasis should once more be laid upon the character of measures on spectra of this nature. It is certainly not too much to say that ranges of at least 5 km between succes-

[1] *Standard Clock and Zodiacal Stars.*

[2] "Relative Positions of the Principal Stars in the Group of the *Pleiades.*" *Transactions of the Astronomical Observatory of Yale University*, 1, Part 1, 1887.

sive plates of the same star, or between duplicate measurements of the same plate, may well be expected in the case of any one of the stars in the above list, except perhaps *Maia* and *Taygeta*. Accordingly, care should be taken not to draw conclusions from accordances which may easily be illusory.

I am indebted to Mr. F. R. Sullivan for efficient assistance in guiding during most of the exposures on the stars here discussed.

YERKES OBSERVATORY,
April 25, 1904.

VARIABLE STARS IN NEBULA OF *ORION* IN CONNECTION WITH CHART FOR *T ORIONIS*.

By JOHN G. HAGEN, S. J.

THE variable stars in the Great Nebula of *Orion*, or in the star cluster of this nebula, seem to belong to that peculiar type which has been recognized during the past ten years as the "cluster type." They are generally too faint for telescopes of less than fifteen inches aperture, and are outside the limit of visibility adopted for the *Atlas of Variable Stars*.

The few observers who can reach these *Orion* variables with their instruments will probably find Bond's chart (Vol. V, *Annals of Harvard College Observatory*) a sufficient guide for identification, especially since Hartwig (*A. N.*, **164,** 415, 1904) and Pickering (*Harvard Circular* No. 78) have given Bond's numbers corresponding to many of these variables. The recent publication of six small charts by Wolf (*A. N.*, **164,** 393, 1894) for finding those of his *Orion* variables which are within or near the Great Nebula, suggested the idea of making the chart for *T Orionis* of the *Atlas Stellarum Variabilium* available for the same purpose. It is No. 1986 of Series I.

1. Four of Wolf's circular charts (III–VI) fall on the sheet of *T Orionis*, two of them entirely inside the graduation net. His Chart I contains only one confirmed variable (a_1), and Chart II none, the only variable (b_0) being among the suspected variables (No. 3) of Professor Pickering's Circular.[1] Thus out of the 14 variables on Wolf's charts, 12 fall on the sheet of *T Orionis*, one-half of them within the net.

Professor Pickering's *Circular* No. 78 contains 71 well-confirmed variable stars and 35 suspected ones. Of these variables, 57 (not identical with any of Wolf's) can be conveniently plotted on the sheet for *T Orionis*, viz., 40 well-confirmed and 17 suspected variables. Some other stars of the circular which would fall on the printed title of the sheet are not counted.

[1] Another chart, recently published by Wolf (*A. N.* **165**, 30, 1894), contains one variable, about four degrees north of *T Orionis*.

Adding to these 69 variables *T Orionis*, and another star found to vary by the writer, and two more stars suspected of variability by Pogson and Schmidt, we shall have 73 variable stars, more or less confirmed, on the single Atlas chart prepared for *T Orionis*.

2. In order to facilitate the identification of these objects, a list of 104 stars has been prepared. Among these are 25 which were merely copied from the catalogue of the Atlas, and are printed on the chart. They fall within Wolf's Charts IV and VI (except two), and can readily be identified on them. Five of these 25 stars are variables (confirmed or suspected), one of them being *T* and the others Nos. 66, 35, 60, 19 of the Atlas catalogue. The remaining 79 stars of the list will have to be plotted on the sheet for *T Orionis*. Eleven of them represent the *B. D.* stars within Wolf's Charts III and V, but without the net of the Atlas. The other 68 stars are variables (in the sense before mentioned), and, together with the five copied from the Atlas catalogue, make up the number 73 of the preceding paragraph.

After these 79 stars are plotted, it will be found convenient to have the four circles drawn which represent Wolf's Charts III–VI. The fainter stars of these charts (the co-ordinates of which were not given) may then be inserted from eye estimates. The common radius of these circles is $10'.5$, which is to be measured from the net of the chart for *T Orionis;* and their centers relative to the middle of the chart (including I and II, which fall outside the sheet) have the co-ordinates:

Chart I	$\Delta\alpha = +5^m\ 40^s$,	$\Delta\delta = +81'.1$
II	$-3\ \ 42$	$+25.4$
III	$-1\ \ 26$	$+46.1$
IV	$-0\ \ 49$	-10.0
V	$-0\ \ 12$	$+37.0$
VI	$+0\ \ 25$	$+13.1$

3. The subjoined list of 104 stars is constructed as follows: The first column gives the numbers in Professor Pickering's *Circular* 78, those in parenthesis referring to his Table II of suspected variables. The next two columns contain exclusively Wolf's designation in his article in *Astronomische Nachrichten*, No. 3935, to make his variables and reference stars recognizable

at a glance. The column headed "Chart" designates Wolf's Charts III–VI on which the stars fall. The heading "*A. S. V.*" denotes the numbers of the Atlas for the 25 stars copied from its catalogue. In the column "Mag." the letter *v* marks the certain variables, while the interrogation point (?) refers to the unconfirmed variables. The magnitudes are those of the Atlas, except for stars outside the net, for which the *B. D.* magnitudes are given. The $\Delta\alpha$ and $\Delta\delta$ denote the co-ordinates of the stars relative to the center of the chart. They were computed from the lists of Wolf and Pickering, and hold for 1900.

P	Wolf		Chart	*A.S.V.*	Mag.	$\Delta\alpha$	$\Delta\delta$
2					*v*	$-2^m\ 29^s$	$+\ 6'.3$
3	36.1903	d_1			*v*	19	+16.3
4					*v*	19	+44.8
5					*v*	19	+44.2
6					*v*	16	+26.7
(6)					?	5	− 2.9
(7)	81.1901	o8	III		?	2 2	+49.6
9					*v*	1 57	−13.4
10	37.1903	d_0	III		*v*	56	+40.4
12					*v*	47	− 8.7
13					*v*	44	+14.6
14			III		*v*	41	+38.3
(8)					?	41	− 3.9
15					*v*	35	+23.8
	−4°1167	*1	III		7.5	29	+39.5
17					*v*	27	− 2.6
(9)					?	27	+31.3
			III		9.5	25	+54.6
18			III		*v*	25	+42.9
			IV	43	10.1	17	−17.4
	−5°1301	*1	IV	23	9.2	16	−14.4
			IV	20	9.1	15	−12.9
19					*v*	13	−37.2
20			IV		*v*	13	− 6.6
21					*v*	10	+ 5.6
22			IV		*v*	9	−17.7
23					*v*	7	+17.6
	−5°1305	*2	IV	11	8.4	3	− 5.7
24					*v*	1	−29.6
25	39.1903	k_0	III		*v*	1 1	+48.2
			IV	41	9.8	0 59	− 4.8
(10)					?	59	+24.9
			III		9.3	57	+43.0
			IV	18	9.0	54	− 2.1
26	40.1903	d_2	IV		*v*	54	−18.3
27			IV		*v*	54	−13.3
29					*v*	52	−26.2
30			V		*v*	−0 51	+37.6

P	Wolf		Chart	*A.S.V.*	Mag.	$\Delta\alpha$	$\Delta\delta$
(12)					?	$-0^m\ 51^s$	$+\ 5'.4$
(13)			IV		?	50	−16.1
					?	48	−32.2 (1)
	−4°1179	*2	III		8.0	47	+44.9
(14)					?	45	+ 3.1
31			IV		*v*	44	− 7.9
33			IV		*v*	43	− 8.7
(15)			IV		?	42	− 3.1
34	41.1903	c_0	IV		*v*	40	−18.1
			V		9.5	39	+36.8
(16)			IV		?	39	− 2.1
			IV	74	13.7	39	− 9.6
35	42.1903	c_2	V		*v*	38	+42.7 (6)
			IV	72	12.3	37	−11.4
36			IV		*v*	36	−14.8
			IV	15	8.8	36	−21.6
37			IV	66	*v*	34	−10.8 (2)
38					*v*	34	−23.7
			IV	73	13.3	32	−14.4
39			V		*v*	32	+34.6
(17)			IV		?	31	− 2.9
40			V		*v*	30	+46.2
	−4°1185	*1	V		4.5	29	+37.9
41	43.1903	l_0	IV		*v*	29	− 6.2
			IV	71	12.0	26	− 2.4
42					*v*	26	+18.7
43					*v*	25	+17.4
44					*v*	24	+ 2.8
			IV	27	9.3	23	−19.8
			V		9.0	22	+34.5
45			V		*v*	22	+33.3
			IV	35	?	19	− 4.5 (3)
			V		8.7	19	+39.0
(18)					?	19	−34.7
(19)			V		?	19	+39.6
46	83.1901	14	V		*v*	16	+27.3
48					*v*	16	+ 6.9
			VI	44	10.1	15	+16.8
	−4°1188	*2	V		6.0	12	+37.0
49				60	*v*	9	+ 0.3 (4)
50					*v*	9	+22.7
			VI	55	10.5	8	+ 8.7
			VI	62	10.9	8	+15.0
(20)					?	5	+ 0.4
51			V		*v*	4	+27.3
			VI	69	11.7	3	+12.0
52					*v*	2	−21.1
53				*T*	*v*	∓ 0	0.0
	8.1904	b_3	VI		*v*	0	+12.0
54	44.1903	a_0	V		*v*	1	+41.3
(21)					?	1	−23.2
55					*v*	2	+24.4
(22)					?	3	+ 2.1
(23)	84.1901	15	V		?	4	+31.6
			VI	21	9.1	+0 8	+ 6.3

P	Wolf		Chart	*A.S.V.*	Mag.	$\Delta\alpha$	$\Delta\delta$
(24)					?	$+0^m\ 9^s$	$-28'.9$
			V		9.5	9	+32.1
			V		9.5	10	+43.1
58					*v*	13	+46.9
63	85.1901	16	VI			25	+16.9
	$-5^\circ.1335$	*1	VI	19	*v*	37	+ 4.2 (5)
			VI	56	10.5	41	+ 5.4
(25)			VI		?	41	+11.6
65					*v*	47	+ 2.5
	$-5^\circ.1338$	*2	VI	17	9.0	48	+21.3
			VI	42	10.0	+0 49	+ 8.7

REMARKS.

(1) This is Bond's star 539, to which Pogson (*Second Madras Catalogue*, 1162) applied the name of *T Orionis*. In the *Cordoba General Catalogue* (6469) it is marked "var.," and it occurs in Chandler's *Catalogue III* under the suspected variables as No. (1980). (See *A. N.*, **163**, 117, Remarks to 1986.)

(2) In the Remarks of Pickering's *Circular* the variation of this star is described as small, but readily observed. When the chart for *T Orionis* was made, this star was marked as suspected of variability, on the ground of the following observations (expressed in the scale of the Atlas *Catalogue*):

1893, Dec. 12 (sky I): Step: 41, mag. 11.5.
1894, Jan. 12 (sky I): Step: 33, mag. 10.8.

(3) and (4) These two stars are Bond 746 and 784 respectively. Their variability was announced by Schmidt, but not confirmed by Chandler. In the latter's *Catalogue III* (note to No. 1986) several other stars are mentioned as probably variable, which do not occur in Professor Pickering's list.

(5) The variability of this star was suspected when the chart for *T Orionis* was made. About 180 estimates of brightness between the years 1891 and 1895 seem to indicate a period of 31 days and a fraction, but the variation is confined to the limits $9^m.0$ and $9^m.3$.

(6) The $\Delta\alpha$ of this star is taken from the publications of Pickering and Hartwig mentioned in the introduction. According to Wolf, $\Delta\alpha = -35^s$. However, Chart V will insure the identification of the variable.

GEORGETOWN COLLEGE OBSERVATORY,
April, 1904.

NOTE.— It is the author's intention to construct, for publication in this JOURNAL, a special chart based on the above list of stars, which will be available when the constellation of *Orion* can be again observed.— EDS.

OBSERVATIONS WITH THE BRUCE SPECTROGRAPH.

By EDWIN B. FROST and WALTER S. ADAMS.

FOUR STARS WHOSE RADIAL VELOCITIES VARY.

RECENT plates taken with the Bruce spectrograph have established the variation of the following stars having spectra of the *Orion* type. The number of stars of this type so far found with this instrument to be variable in their radial velocities thus becomes thirty-six.

9 *Camelopardi* ($\alpha = 4^h\ 44^m$; $\delta = +66°\ 10'$; Mag. = 4.4).

Plate	Date	G. M. T.	Taken by	Velocity F.	Velocity A.	No. of Lines F.	No. of Lines A.	Velocity Mean
				km	km			km
IB 194	1903, Nov. 17	$15^h\ 9^m$	A.	+14	+ 6	5	3	+10
229	Dec. 26	21 59	F.	+ 3	− 2	3	4	+ 1
254	1904, Jan. 2	21 30	A.	+01	+14	2	3	+12
	Second Component			− 9	− 6	2	2	− 8
285	1904, Feb. 26	17 10	A.	+ 9	+13	6	4	+11
	Second Component			+ 2	+ 3	2	2	+ 3
288	1904, Mar. 8	17 21	F.	− 6	− 7	3	5	− 7
	Second Component			+ 8	+ 6	2	2	+ 7
296	1904, Mar. 19	16 2	A.	− 1	+ 4	3	4	+ 2
	Second Component			−12	−12	2	2	−12

It was our first intention to include this star with the list of eight in our communication in the March number of this JOURNAL, but measures on the sharp and brilliant H and K lines gave results which were not accordant with the values derived from the remaining very diffuse lines in the spectrum, and publication was deferred until further plates were secured. The last four plates, which were exposed so as bring out well the region of H[1] and K, permitted excellent determinations of the radial velocity of the body producing those lines, and clearly show the existence of two components. Meanwhile Professor Hartmann's interesting article on δ *Orionis*, published in the May number of this JOURNAL, came to our attention. He finds that

[1] H is well separated from the adjacent hydrogen line $H\epsilon$, so that the accuracy of the settings is not affected by the proximity.

the K line in that spectroscopic binary does not share in the large radial velocity of the body in which the diffuse lines originate, and he believes that the K line does not "oscillate," attributing the range of 21 km in his measures to errors of observation. The K line on his plates of δ *Orionis* must be much less sharp than in the case of our star, which happens to show, so far, the same range of 20km (for the mean of the velocities of H and K). Here, however, the lines are so well defined that we can hardly think our determinations of the velocity from H and K (mean for the two observers) uncertain by more than 3km, to judge by the accordance of the independent measurements.

κ *Cancri* ($\alpha = 9^h\ 2^m$; $\delta = +11^\circ\ 4'$; Mag. = 5.0).

Plate	Date	G. M. T.	Taken by	Velocity		No. of Lines		Velocity Mean
				F.	A.	F.	A.	
				km	km			km
IB 256	1904, Jan. 2	$22^h\ 44^m$	A.	+ 2	+ 3	7	6	+ 2
267	Jan. 23	20 44	A.	+ 92	+ 84	4	5	+ 88
F 286	Feb. 26	18 38	A.	+ 37	+ 33	5	5	+ 35
	Second Component			−134	−136	1	1	−135
289	Mar. 8	18 36	F.	+ 82	+ 83	9	5	+ 83
	Second Compon't[1]			− 88	− 56	2	3	...
305	April 15	15 25	A.	+ 72	+ 68	4	5	+ 70
	Second Component			−105	− 90	2	2	− 97

The investigation of this star has proved of especial interest because of the presence of the second component. The lines in the case of the latter are very faint, and settings upon them are subject to considerable uncertainty, but their existence is unmistakable. The spectrum of the principal star has narrow, well-defined lines, particularly of hydrogen and magnesium, helium being very faintly represented. The spectrum of the second star seems to be of a similar type.

μ *Sagittarii* ($\alpha = 18^h\ 8^m$; $\delta = -21^\circ\ 5'$; Mag. = 4.1).

Plate	Date	G. M. T.	Taken by	Velocity		No. of Lines		Velocity Mean
				F.	A.	F.	A.	
IB 311	1904, April 15	$20^h\ 36^m$	A.	+46	+45	5	5	+46
323	April 16	21 36	A.	+41	+43	5	8	+42
328	April 29	20 59	A.	....	−34	..	4	−34
335	April 30	21 4	F.	−34	....	4	..	−34

[1] Measurements uncertain.

Two determinations by Wright of the motion of this star were published by Campbell in 1901 among examples of stars with large radial velocities.[1] The values were:

1899, June 19	−75 km
1900, May 30	−76 km

The close agreement of the two observations separated by an interval of nearly a year is a remarkable coincidence in view of the large range in the velocity. The spectrum is very similar to that of *β Orionis*, and the lines are well defined and narrow.

δ^1 *Lyrae* ($\alpha = 18^h\ 50^m$; $\delta = +36°\ 51'$; Mag. $= 5.3$).

Plate	Date	G. M. T.	Taken by	Velocity F.	Velocity A.	No. of Lines F.	No. of Lines A.	Velocity Mean
				km	km			km
IB 298	1904, Mar. 19	$20^h\ 22^m$	A.	−79	−96	6	6	−88
308	April 15	18 40	A.	+ 6	+ 9	4	4	+ 7
319	April 16	19 00	A.	+ 4	+13	5	5	+ 8
325	April 29	18 32	A.	− 4	....	4	..	− 4

A plate taken on April 12 by F. shows a large difference as compared with the earlier plate. The exposure was stopped by clouds, however, and the plate is too weak for satisfactory measurement. The lines in this spectrum are diffuse and broad, and seem to be complicated by maxima. Accordingly considerable differences in the results of the two observers may well be expected.

RADIAL VELOCITY OF THE *Orion* NEBULA.

Our recent observations of the three brighter stars of the trapezium of *Orion* have furnished a number of determinations of the radial velocity of the nebula at the different points located by the positions of the stars. The bright nebular lines are superposed upon the spectrum of the star, in the case of the hydrogen lines δ, γ, and β overlying the broad and diffuse dark lines present in all the stars. This does not seem to disturb the accuracy of the settings upon the nebular lines, but the converse is not true, for the presence of the superposed bright lines renders it almost impossible to make a satisfactory setting on the dark star lines.

[1] ASTROPHYSICAL JOURNAL, 13, 99, 1901.

The plates utilized here were all taken with the dispersion of one prism and with a camera of 607mm (24 inches) focal length. While the greater scale of plates taken with three prisms would increase the accuracy of the measurements of the displacements of lines near the center of the field, this would here apply only to a single line, and the advantage would be more than offset by the greatly increased range of good focus (on some plates from λ 3970 to beyond λ 5000) on the one-prism plates. Furthermore, the exposure times required for obtaining the spectra of the stars (except θ^1) would be so long as to make the use of three prisms quite impracticable.

In the case of one exposure, for plate 287, on Bond 619, the "planet window" was used in front of the slit, and the nebular lines therefore extended out beyond the comparison lines, having a total length of about 2.6mm. This corresponds to an angular extent of 44″ in the sky. In this distance on the plate there is no evidence of a departure of the lines from the normal curve for the one-prism arrangement that would suggest any difference of radial velocities in that portion of the nebula included.

The comparison lines which were most frequently used for the different lines follow, with their (solar) wave-lengths according to Rowland. We have employed for the two principal nebular lines the wave-lengths as determined by Hartmann,[1] which yield values accordant with those obtained from the hydrogen lines. They are designated below as N_1 and N_2.

Line	$H\epsilon$	$H\delta$	$H\gamma$	$H\beta$	N_2	N_1
Adopted wave-lengths	3970.177	4101.89	4340.634	4861.527	4959.17	5007.04
Wave-length of comparison lines	*Fe* 3969.413	*Ti* 4078.631 *Ti* 4082.589 *Ti* 4099.327 *Ti* 4112.869	*Ti* 4338.084 *Ti* 4341.530 *Ti* 4344.451	*Ti* 4856.203 *Ti* 4870.323 *Ti* 4885.264	*Fe* 4957.785 *Ti* 4981.912	*Ti* 4999.689 *Ti* 5007.398 *Ti* 5014.369

The results obtained for the radial velocity of the nebula are collected in the following table, which probably requires no further words of explanation.

[1] ASTROPHYSICAL JOURNAL, 15, 290, 1902.

Star	Plate	Date (G. M. T.)	Taken by	Velocity		Lines Used		Velocity Mean
				F.	A.	F.	A.	
				km	km			km
θ^1 *Orionis*	IB 158	1903, Oct. 24.9	A.	+16	+21	γ, β, N_1	γ, β	+19
"	207	Dec. 1.8	F. A.	24	21	γ, β, N_1	γ, β, N_1	23
"	218	Dec. 25.7	A.	18	18	γ, β, N_2, N_1	γ, β, N_2, N_1	18
"	237	Dec. 27.7	A.	21	21	γ, β, N_2, N_1	γ, β, N_2, N_1	21
"	241	Dec. 31.7	F.	19	19	γ, β, N_1	γ, β, N_2, N_1	19
"	248	1904, Jan. 2.6	A.	15	16	γ, β, N_1,	γ, β, N_2, N_1	16
"	283	Feb. 26.6	F.	19	20	γ, β, N_1	γ, β, N_1	19
Bond 640	208	1903, Dec. 1.8	F. A.	15	17	γ, β, N_1	γ, β, N_1	16
"	249	1904, Jan. 2.7	A.	18	21	γ, β, N_2, N_1	$\delta, \gamma, \beta, N_2, N_1$	19
"	284	Feb. 26.6	A.	19	18	γ, β, N_2, N_1	γ, β, N_1	19
Bond 619	287	Mar. 8.6	F.	14	15	$\epsilon, \delta, \gamma, \beta, N_2, N_1$	$\delta, \gamma, \beta, N\ , N_1$	14

The mean velocity from these eleven plates is + 18.5 km.

We cite for comparison the result of other observers as follows:

Keeler[1] (visual, with Lick star spectroscope) - -	1890–91	+17.7 km.
Wright[2] (Mills spectrograph) - - - - -	1901	+16.2
Vogel and Eberhard[3] (Potsdam spectrograph IV) -	1902	+17.4

The low value we get from plate 287, at Bond 619, is rather surprising, as, on account of the excellent quality of the plate, a larger number of lines was measured than usual. We do not wish, however, to draw any inferences from a single plate, and our repeated attempts to secure additional plates this season have been defeated by cloudy weather.

Although our results can at this time be merely provisional in regard to the radial velocities of the three trapezium stars, it may be of interest in this connection to add the values so far obtained. We are not yet prepared to discuss the principal star θ^1 *Orionis*, the binary character of which was surmised by Sir William and Lady Huggins,[4] and confirmed by our observations communicated in the March number of this JOURNAL. The peculiarities of the spectrum are such that its proper discussion

[1] *Publications of the Lick Observatory*, **3**, 217, 1894.

[2] ASTROPHYSICAL JOURNAL, **16**, 58, 1902. [3] *Ibid.*, **15**, 303, 1902.

[4] *Ibid.*, **6**, 323, 1897, also, more fully, in their *Atlas of Representative Stellar Spectra*, pp. 138–142, 1899. We regret that we failed to allude to these observations in our previous article, but unfortunately they escaped us until after the JOURNAL had gone to press.

will require a large number of plates, and the radial velocity of the binary system cannot be given until the orbit is determined.

For the two other stars our results up to the present time can be given. Bond 640 is the following star, and Bond 619 the preceding star, of the four constituting the trapezium.

Bond 640.

Plate	Date	Taken by	Velocity		No. of Lines		Velocity Mean
			F.	A.	F.	A.	
			km	km			km
IB 208	1903, December 1	F. A.	+22	+18	5	4	+20
249	1904, January 2	A.	22	21	4	7	22
284	February 26	A.	17	18	4	5	18
						Mean	+20

Bond 619.

IB 287	1904, March 8	F.	+49	+46	7	8	+48
						Mean	+48

The rather large departure from the radial velocity of the nebula in the case of Bond 619 is interesting, but further plates will be required before any inference can be properly drawn. It is not at all impossible that this star varies in its radial velocity, like θ^1 and the neighboring star θ^2 *Orionis*. In that case we might expect that the radial velocity of the center of gravity of the binary would more nearly coincide with the velocity of the nebula.

THE RADIAL VELOCITY OF STAR C IN THE SYSTEM OF ζ *Cancri*.

The existence of irregularities in the motion of the faintest star in the triple system of ζ *Cancri* was investigated by Seeliger in 1881 on the basis of micrometer measures. He arrived at the conclusion that the star was attended by an invisible companion, and performed a revolution around their common center of gravity in a period of eighteen years. Two determinations have been made by A. of the radial velocity of the star, with a view to detecting such motion. These results are as follows:

C 9	1902, December 17	−12 km
IB 297	1904, March 19	−12 "

The number of lines measured in the two cases was eight and eleven respectively.

Accordingly there is no evidence of change in the star's motion during the interval of fifteen months between the two observations.

NOTE ON γ *Corvi*.

In *Lick Observatory Bulletin* No. 46[1] Messrs. Campbell and Curtis announce that the star γ *Corvi* varies in radial velocity, and give the values derived from six plates, which show a range of 24 km. This star was included in the list for which detailed observations were published in our recent paper on "Radial Velocities of Twenty Stars Having Spectra of the *Orion* Type."[2] It was our intention to exclude from that list all stars whose radial velocities varied, but our observations of this star happened to fall at such dates that no variation could be inferred. The range of velocity (mean for measures by F. and A.) was less than a kilometer for our three plates.

This star should therefore be excluded from the list in our Decennial paper, and its effect upon the mean for the twenty stars corrected. In averaging the proper motions of those stars it was omitted, owing to its relatively high value. Unfortunately our paper had been electrotyped before the Lick results were published, so that we were unable to make the necessary correction.

YERKES OBSERVATORY,
May 5, 1904.

[1] ASTROPHYSICAL JOURNAL, **18**, 307, 1903.

[2] *Publications of the Yerkes Observatory*, **2**, 145–250, 1903.

REVERSALS IN THE SPECTRA OF SUN-SPOTS.

By Walter M. Mitchell.

In observing the spectra of Sun-spots during the latter part of March and during April, a large number of lines were seen reversed. The first observation was on March 24 on a spot near the south following limb of the Sun. The second observation was made on March 30 on the same spot, which by this time had moved considerably past the center of the disk. The third observation was on April 15, on the large spot of the group which was visible during that week. The fourth and last observation was made on April 22, on a large spot on the north following limb. The spot had apparently come around a day or so before. For convenience the observations will be designated by (1), (2), (3), and (4).

On the first three dates the region of the spectrum observed extended from λ6600 in the red to λ5700 in the yellowish-green. On the fourth date the region observed was from λ6770 to C, and from λ6100 to F. All the observations on the last date were very unsatisfactory, the seeing was bad, and the spot, being very near the limb, presented a line instead of the usual round image.

All observations were made with the spectroscope of the 23-inch refractor of the Halsted Observatory, in the third-order spectrum of a Rowland grating of $4 \times 2\frac{1}{2}$ inches ruled surface—20,000 lines per inch.

In the whole region above mentioned from λ6770 to λ4915, over 270 lines have been observed as more or less affected in the spectra of Sun-spots. In the following preliminary list only the lines reversed are given.

The wave-lengths were read off from Rowland's photographic map, and afterward corrected to two decimals with the aid of Rowland's *Table of Solar Spectrum Wave-Lengths*.

In looking over the unpublished observations of Professors Young and T. Reed, made in 1892 with the same instrument, I have found that several of the lines were seen reversed at that time. These are indicated by a (Y).

Wave-Length	Element	Remarks
5250.39 s	*Fe*	(4) Reversed.
5432.75	*Mn*	(4) Strongly reversed.
5538.74	*Fe*	(4) Reversed.
5712.36	*Fe*	(1) Strongly reversed and on (4) medium reversal.
5727.87	*V?*	(4) Strongly reversed.
5731.48	*V*	(1) and (4) Strongly reversed.
5746.5 ?	....	(4) Strongly widened, reversed? There is apparently no corresponding dark line in the spectrum. Rowland gives an A line at λ 5746.64.
5748.57	*Ni*	(4) Medium reversal. (Y)
5781.13	*Cr–Ti*	(1) Medium reversal.
5781.40	*Cr*	(1) Strong reversal. (4) Medium reversal. (Y)
5781.97	*Cr*	(1) and (4) Much widened, strongly reversed. (Y)
5783.29	*Cr*	(1) and (4) Medium reversal. (Y)
5784.08 s	*Cr*	(1) Medium widening, but strong reversal. (Y)
5784.88	*Fe*	(1) Medium widening, but strong reversal; (4) Faintly widened, but still reversed. (Y)
5785.19	*Cr*	(1) Strong reversal. (4) Medium reversal. (Y)
5785.50	*Fe*	(1) Medium reversal.
5798.08 s	....	(4) Reversed?
5880.83	*La?*	(4) Strong reversal.
5910.20	*Fe*	(4) Strong reversal.
5918.77	*Ti*	(4) Strong reversal.
5938.04	....	(4) Strong reversal.
5958.46	....	(4) Strong reversal.
5999.92	*Ti*	(4) Medium reversal.
6002.97	....	(4) Reversed.
6005.77	*Fe*	(1) and (2) Medium widening reversed? (3) and (4) Widened and reversed.
6008.19 s	*Fe*	(1) Medium reversal. (3) Reversed? (4) Strongly reversed.
6012.45	*Ni*	(1) Medium reversal. (2) Strongly reversed. (4) Faint, but reversed.
6013.72 s	*Mn*	(1) Slightly widened, reversed. (4) Medium reversal.
6016.86 s	*Mn*	(1) Slightly widened, reversed. (4) Medium reversal.
6039.95	*V*	(2) and (3) Strong reversal. (4) Medium reversal.
6064.85	*Ti*	(1) Wide reversal. (3) and (4) Strongly reversed.
6079.23 s	*Fe*	(1) and (2) Medium reversal. (3) and (4) Strong reversal. (Iron line at λ 6078.71 observed "widened" on (2) only. Not affected in any other observation.)
6081.67	*V*	(3) and (4) Strong reversal.
6082.93	*Fe*	(1) and (2) Strongly reversed. (3) and (4) Strong reversal extending into penumbra. (Y)
6085.47	*Ti–Fe*	(4) Medium reversal.
6089.79	*Fe*	(2) Fine thin reversal.
6090.43	*Fe–V?*	(1) Strongly widened, reversed? (4) Strong reversal.
6091.40	*Ti?*	(4) Medium reversal.
6093.03	*Ti?*	(4) Scarcely widened, but reversed.
6093.37	*Mn*	(3) and (4) Scarcely widened, but reversed.
6096.88	*Fe*	(3) and (4) Medium reversal.
6098.46	....	(3) and (4) Slightly widened, reversed.
6102.94 s	*Ca*	(1) and (4) Strong reversal.
6111.87	*V*	(3) Strongly reversed.
6126.44	*Ti*	(1) and (2) Medium reversal.
6129.19	*Ni*	(3) Slightly widened, reversed.

Wave-Length	Element	Remarks
6137.21	*Fe*	(1), (2), and (3) Strong reversal extending into penumbra. (Iron lines at λλ 6136.83 and 6137.92 not affected in any way on any date.)
6150.36	*V*	(1) Strongly reversed.
6151.83	*Fe*	(1) and (2) Strongly reversed. (3) Reversal extending into penumbra. (Y)
6151.44 s	*Na*	(1) Medium reversal. (4) Strong reversal.
6163.97	*Ca*	(3) Strongly widened, reversed ?
6173.55 s	*Fe*	(1) Strong reversal extending beyond umbra. (2) Strong reversal. (3) Strong reversal, possibly double reversal.
6188.21	*Fe*	(1) and (3) Medium reversal.
6240.86	*Fe*	(1) and (3) Medium widening, reversed ?
6243.06	*V*	(1) and (2) Medium reversal.
6243.32	*V*	(1) Strongly reversed. (3) Much widened, reversed ?
6246.54 s	*Fe*	(1) Medium reversal.
6252.05	*V*	(1) Strongly reversed.
6259.0	....	(1) Medium widening, reversed. (No corresponding dark line in spectrum.)
6266.55	*V*	(2) Seen widened. Reversed by (Y).
6285.38	*V*	(3) Medium reversal.
6302.71	*Fe*	(3) Strongly reversed.
6316.03	*Fe*	(3) Reversed ?
6327.82	*Ni*	(3) Medium reversal.
6330.31	*Cr*	(3) Reversed. (Y)
6337.05	*Fe*	(3) Medium reversal.
6363.09	*Cr–Fe*	(3) Medium reversal.
6380–6400	....	Spectrum of spot on April 15, resolved into 17 groups of fine lines (similar in appearance to G under low dispersion). Also observed by (Y).
6499.17	*Fe*	(3) Strongly widened, reversed.

In addition to the above lines observed reversed the following lines were seen diminished in width or "thinned."

6191.39 s	*Ni*	(3)
6432.89	*Fe ?*	(3)
6496.0 ? } 6496.69 }	*Fe*	(3) Appearance very similar, thinned or possibly a hazy reversal.
6546.48 s	*Ti–Fe*	(3)

In the region C–D the reversals are about 35 per cent. of the whole number of lines affected. About 5 per cent. more were observed "reversed?" In this case the appearance was too uncertain to determine whether the line was reversed or not. The C line was observed partially reversed over a spot on April 8. The *b*'s, the E's, and the D's have not been affected in any way. The helium line D_3 was not visible in any observation.

THE OBSERVATORY, PRINCETON, N. J.,
May 3, 1904.

RESEARCHES ON THE SYSTEM OF THE SPECTROSCOPIC BINARY β *AURIGAE*.[1]

By H. C. Vogel.

The discovery of spectroscopic binaries is in general possible only with the use of slit-spectographs of high dispersion, by means of the accurate measurement of the displacements of the lines of the stellar spectrum as compared with lines in the spectrum of a source of light at rest. The periodic variations of the component of the velocity in the line of sight then furnish the data for investigations on the orbits of the stars, even if only one component of the pair is visible. If the two components are of about equal brightness, a case which does not appear to occur often, a periodical displacement of the superposed spectra of the two bodies will be the result of their revolution, provided the plane of their motions is not too nearly perpendicular to the line of sight. Hence those lines which are due to elements which are present in the luminous atmospheres of the two heavenly bodies will be periodically doubled. In this case we may investigate the period of revolution as well as the further elements of the orbit of the binary on the basis merely of the measurements of the separation of the doubled lines; and if we forego the determination of the radial velocity of the system, a slit-spectrograph is not essential for the observation of such a binary; plates taken with objective-prisms are sufficient.

The second-magnitude star, β *Aurigae*, is one of the leading representatives of this class of spectroscopic binaries. To judge by the intensity of the spectrum lines, the two components are here equally bright, and the spectra of both bodies belong to the type I*a*2, having comparatively few lines.

The binary character of the star was discovered in 1890 in the course of the spectrographic *Durchmusterung* undertaken some fifteen years ago by E. C. Pickering at the Harvard College

[1]Translated from advance proofs, sent by the author, of a paper to appear in the *Sitzungsberichte der Kgl. Akademie der Wissenschaften zu Berlin.*

Observatory.[1] The numerous photographs of the spectrum of this interesting star taken continuously there furnished further data for extensive investigation.

On the two dates, November 14, 1888, and January 3, 1889, a plate of the spectrum of the star was obtained at the Potsdam Observatory in the course of the researches on the motion of the stars in the line of sight conducted by myself during the years 1888 to 1891. On both plates are found two lines of almost equal intensity at the position of the magnesium line at $\lambda 4481$. The spectrograms at that time covered only a small portion of the spectrum in the neighborhood of $H\gamma$, and in addition to this hydrogen line and the double line mentioned only a few extremely delicate lines could be recognized in the star's spectrum. To our limited knowledge of this region in stellar spectra at that time the occurrence of a double line presented nothing surprising, but if the spectrum had been repeatedly photographed the variation in the separation of the two lines could, however, not have been overlooked. As soon as the discovery of the binary nature of *β Aurigae* became known, five further plates of the spectrum were made at my request by Professor Scheiner, who was then assisting me in my observations, and on measuring these plates I was able to confirm most fully the results obtained at Cambridge. I collected my measurements and the conclusions derived from them in December 1890, and they were published in *Astronomische Nachrichten* (**126**, 265, 1891), and later (in 1892), with some additions, in Part I of the seventh volume of the *Publicationen* of the Astrophysical Observatory at Potsdam (pp. 139 *et seq.*).

I would here call especial attention to the fact that I then found that the relative intensities of the components of the *Mg* line at $\lambda 4481$ were subject to change, since on some plates the component lying toward the red, and on others the component toward the violet, had slightly greater intensity. I further took pains to determine whether the masses of the two bodies could be regarded as nearly equal; or, in other words, whether the center of gravity of the system lay nearly midway between the

[1] Henry Draper Memorial, Fourth Annual Report, 1890.

two bodies or nearer to one of them. The observations were rendered difficult by the fact that at that time hydrogen was the only comparison spectrum used on the plates. My studies led to the statement: "The agreement [of the measurements cited] leaves no doubt that the orbital velocities of the two bodies are only slightly different from each other at the time of greatest elongation" (*loc. cit.*, p. 143). I add here a few further paragraphs from this monograph (pp. 143 and 144).

It would, in my opinion, be of little purpose to add here further observations as to the periodic doubling of the lines in the spectrum of *β Aurigae*, since the period of revolution of the two stars can be determined with great accuracy from the large amount of observational data collected at Cambridge. Pickering has given in the January number of the *Sidereal Messenger* for 1891 a short provisional statement as to the period yielded by the Cambridge observations, which was: Period of revolution $3^d\ 23^h\ 36^m.7$ ($3^d.9838$); lines in the spectrum single at approximately Greenwich mean noon on January 1, 1891.

On the assumption that the greatest separation of the line corresponds to twenty-eight (German) geographical miles, I have computed back with this period to the Potsdam observations, and have found the best agreement on assuming January 1, 1891, 3^h G. M. T., for the epoch of single lines. (A table follows.) I would add for further characterization of the binary system, and for making complete the above statement, that on January 2, 1891, at 3^h G. M. T., the more refrangible of the separated lines was the stronger.

On the assumption of a circular orbit with a slight inclination to the line of sight, taking the period as an even four days and the velocity as fifteen geographical miles, the separation of the two bodies would be 1,650,000 (German) geographical miles and the mass of the system would be 4.7 ⊙.

In describing a method of determining the orbit of spectroscopic binaries in the number of *Monthly Notices* for March 1891,[1] Mr. Rambaut derived for *β Aurigae* from the Cambridge observations a period of $3^d.968$ ($3^d\ 23^h\ 14^m$). He finds further that the orbit is an ellipse with an eccentricity $e = 0.156$, and he calculates the mean separation of the bodies as 7,500,000 (English) miles (in round numbers 12,000,000 kilometers).

The number of the ASTROPHYSICAL JOURNAL for October 1898[2] contains an article by Miss A. C. Maury, entitled "The K Lines of *β Aurigae*," in which it is stated that 200 spectrograms of this star were obtained at the Harvard Observatory in the

[1] 51, 316. [2] 8, 171 *et seq.*

nine years from 1889 to 1898. Observations were made with objective-prisms attached to the eleven-inch Draper telescope in each year, with the exception of the winter of 1896–7. Two prisms were used for 120 of the plates, while three and four prisms were used for the remaining 80 plates.

The following data are communicated as to the system: period $= 3^d\ 23^h\ 37^m$; relative velocity $= 240$ km; distance of the two bodies = about 8,000,000 English miles, on the assumption that the line of sight is in the plane of the orbit; mass of the separate components $= 1.25\ \odot$. The period is therefore the same as that given by Pickering in 1891 in the *Sidereal Messenger.*

The main feature of the article is an investigation as to the relative intensity of the components of the K line. As I had previously announced in December 1890, the components of the *Mg* line at λ 4481 are subject to a variation in respect to their relative intensities, and in her examination of the great number of plates collected at Cambridge, which extend farther into the violet, Miss Maury found the same to be true for the K line (λ 3934), which is still stronger in the spectrum of *β Aurigae* than the *Mg* line. Unfortunately these investigations, and the conclusions from them, are in error, as I shall show below.

OCCASIONAL OBSERVATIONS OF *β Aurigae* AT THE POTSDAM OBSERVATORY.

Since 1891 only occasional plates of the spectrum have been obtained. Thus in 1897 Professor Hartmann made a few plates of the spectra of the brighter stars with the spectrograph of 1888 attached to the Schroeder refractor, and among these there is one plate of *β Aurigae* on which the *Mg* lines are separated. The component toward the violet is broader and more diffuse than the other, which renders the measurement difficult; and, on account of the unfavorable conditions under which it was taken, the plate is in any case of only slight reliability. I cite the observation, as it may nevertheless be utilized for confirming the correctness of the period derived below. The result was that on 1897, November 10.378, Central European Time, the relative motion of the components was 205 km per second.

For the same reason I mention here a few further plates secured with Spectrograph D in connection with the 33 cm photographic refractor. In spite of the low dispersion of this spectrograph, it is nevertheless possible to recognize with some certainty the phase of the component of the binary star. It is fortunate that the spectra extend far into the ultra-violet, and that the K line, which, as already mentioned, is sharp in the spectrum of β *Aurigae*, can be measured with some accuracy on account of the greater linear extent of the more refrangible regions in the prismatic spectrum.

The first plate was taken by Professor Wilsing for the spectrographic researches carried on by myself in conjunction with him.[1] The result was that on 1896, May 7.456, C. E. T., K was widely separated, corresponding to a relative velocity of 227 km.

The further plates with Spectrograph D were obtained by Drs. Eberhard and Ludendorff, who were engaged for a considerable time in an investigation of the most refrangible part of stellar spectra, for which its great light-power made instrument D especially suited. They extended their investigations as far as to λ 3550. The regions in the neighborhood of $H\gamma$ are greatly overexposed on all of the plates taken for the above purpose, and even the region around K is generally somewhat too long exposed. The plates were made with as narrow a slit as possible (0.01 mm), and the components of the K line are therefore very sharp and well measurable. I used various magnifying powers in making the measures.

1899	Relative Velocity	Remarks
March 5.50 C. E. T.	About 100 km	K appears as a broad line, perhaps double.
11.50	...	K single, broad.
12.43	...	K widely double. Plate overexposed.
12.49	212	K widely separated; very reliable measure.
14.46	217	Very reliable measure.
15.43	About 100	K perhaps double.
17.44	...	K pretty narrow and sharp.

Measurements show that the components were very nearly at the maximum separation on March 12 and 14. On account

[1] *Publicationen des Astrophysikalischen Observatoriums*, **12**, 39, 1899.

of the low dispersion, a separation of strong lines corresponding to a relative motion of 100 km could not be expected; hence the other spectrogram on which K is single would by no means necessarily represent the dates of perfect superposition of the lines.

After I had succeeded (from my measures of the numerous plates obtained by Messrs. Eberhard and Ludendorff with Spectrograph IV attached to the 33 cm refractor in the spring of 1901) in finally disentangling the relations in the spectrum of *ζ Ursae Majoris*,[1] which was discovered simultaneously with *β Aurigae* in 1890, and resembles it in respect to the doubling of the lines, my desire was aroused to again occupy myself with a thorough investigation of the system of *β Aurigae*. I therefore requested Professor Hartmann to obtain for the studies I had in view spectrograms of this star with Spectrograph I attached to the 80 cm refractor. The plates of other stars obtained by Professor Hartmann with this single-prism spectrograph extend far beyond K, and are remarkable for the fact that they possess an extraordinary and almost uniform sharpness over the whole region from $H\beta$ to $H\zeta$. Unfortunately, only four plates of *β Aurigae* were obtained on four successive days—on two days very nearly at the epoch of maximum separation, and on the other two at the epoch of minimum separation.

I now communicate my measures and observations on these very successful plates.

1901, September 23, 12^h 20^m C. E. T.—K is double, the lines being nearly equally broad, with the less refrangible one slightly the broader and somewhat less sharply bounded. The distance of the two lines was 0.662 rev. = 0.1655 mm, according to numerous measures made with different powers and with single and double threads, as well as with the plate in different positions under the microscope. In spite of their width and diffuseness, all the hydrogen lines from $H\beta$ to $H\zeta$ are clearly separated. The well-pronounced intensity-maximum can be set on quite accurately. But neither the $H\epsilon$ line nor the adjacent

[1] *Sitzungsberichte der k. Akad. zu Berlin*, **24**, 534, 1901; ASTROPHYSICAL JOURNAL, **13**, 324, 1901.

Ca line are adapted for measurement, as the latter still falls within the shadow of the broad $H\epsilon$. My measures give for the separation of the line 0.612 rev. for $H\delta$, and 0.480 rev. for $H\gamma$, Numerous fine lines in the spectrum appear double.

A displacement of 1 rev. corresponds to a velocity of 334.1 km at K, 386.7 at $H\delta$ and 464.4 at $H\gamma$, whence we get for the relative velocity of the two bodies the values: 221 km(5), 237(2), and 223(1). The numbers in parentheses give the weights which I have assigned in averaging the values in the summary below. The decidedly large weight is given to K on account of its superior sharpness, the greater number of measures upon it, and the greater linear extent of the separation.

September 24, 13^h 17^m C. E. T.—The K line appears single, but very wide. From the measured width, combined with the measurements of the width of the separate components of the previous day, I determined the relative displacement to be 0.114 rev., although with only slight reliability (the four plates of *β Aurigae* were taken with the same slit-width and under favorable conditions, and the two spectra of each pair are so similar that they might be exchanged). Between $H\beta$ and $H\zeta$ there can be seen on this spectrogram from 55 to 60 fine lines, many of which coincide with the lines of the iron spectrum.

September 25, 13^h 24^m C. E. T.—K is double, with the less refrangible component somewhat narrower than the other, though the difference is hardly appreciable. The separations and corresponding relative velocities are as follows: K (from many measures), 0.629 rev. = 210 km(5); $H\delta$, 0.557 rev. = 215 km(2); $H\gamma$, 0.498 rev. = 231 km(1).

September 26, 12^h 52^m C. E. T.—K is central and with sharp edges, and is of almost the same width as on the spectrogram of September 24. The spectrum is very rich in fine lines, which appear more distinctly than on the plate of September 24. I could see 8 lines between $H\zeta$ and K, 5 between K and $H\epsilon$, 14 between $H\epsilon$ and $H\delta$, 34 between $H\delta$ and $H\gamma$, and 16 in the somewhat overexposed portion of the spectrum from $H\gamma$ to λ 4550. I derived the relative motion of the two bodies as 46 km from measurements of a double iron line and from measures of the width of K.

The results of the measurements of the relative velocities of the components of the binary system on the four plates are accordingly

1901, Sept. 23.514 C. E. T.	- - -	225 km
24.553	- - - -	38:
25.558	- - - - -	214
26.536	- - - -	46:

As the star spectrum was inclosed by a comparison spectrum of iron, the radial velocity of the system could also be derived from the displacement of the K line, on the assumption that the components are of equal mass. The separate plates yielded the following values for the velocity of the system relatively to the Sun:

Sept. 23 =	−20.6 km
24	−14.0
25	−20.7
26	−14.1

In obtaining the displacement for September 23 and 25, when K was double, the mean was simply taken from the measures of the individual lines, and the components differed in phase by 180°. Hence we may conclude from the agreement of the two series of measures that the center of gravity of the system must actually have been situated very nearly centrally between the two bodies. This confirms my earlier observations above cited, which, of course, depend upon much less accurate material. It would appear surprising that the values agree in pairs, their means differing from each other by 6.6 km, which corresponds to a linear displacement of 0.005 mm on the plate. On September 24 and 26 the K lines are nevertheless no longer separated, but constitute a broad line, the center of which does not coincide with the middle point between the lines of which it is composed, if the components of the line differ in intensity and width. (I therefore give the observations of the two days a weight of two-thirds.)

The above observations having been made very nearly at the maximum and minimum separation of the lines, an appreciably different phase in the position of the body could not be expected for a considerable time, as the period was very nearly four days. The repetition of the observations, however, was finally given up,

since it appeared that Hartmann's plates could be represented (purely accidentally, as turned out later) with Pickering's period from the zero epoch given by me as 1891 January 1, 3^h G. M. T.

I therefore considered that the period required no serious corrections, since it was again employed by Miss Maury without change after the conclusion of the nine-year series of observations. My surprise was therefore not small when an article appeared in *Astronomische Nachrichten*[1] by Mr. G. A. Tikhoff, who on measuring the spectrograms of *β Aurigae* taken by Mr. Bélopolsky at the Pulkowa Observatory in 1902 and 1903, arrived at very peculiar results, wholly contradictory to the previous views.

ON THE DISCUSSION BY G. A. TIKHOFF OF THE SPECTROGRAMS MADE AT PULKOWA.

Mr. Tikhoff finds, in the first place, that the period of revolution of the two bodies is six minutes shorter (he gets $P = 3^d\,23^h\,30^m.4$) than Pickering had stated, and he suspects that it may have changed in the course of twelve years. This would not be unlikely, since he considers that *β Aurigae* must be regarded as a highly complicated system, consisting of four bodies instead of two. His curve representing the relative velocities during a period has the form shown in the figure. He explains it as the result of the superposition of two sine curves, one of which has the period just cited of nearly four days, while the other has a period exactly one-fifth of this ($19^h.1$). It is not at present possible to separate the two curves, as the combined curve is not yet sufficiently well known in all its parts. From the occasional doubling of the components of the single line which he perceived on some of the plates (for instance, on January 21, 1904, $H\gamma$ is resolved into four components having relative velocities, for the different combinations, of 1–2, 46 km; 1–3, 224 km; 3–4, 43 km; and 2–4, 221 km), Mr. Tikhoff arrived at the conclusion that *β Aurigae* is composed of two groups of bodies, each of which consists of a star with strong lines and a second star with weak lines. The period of revolution of the

[1] "Recherches sur les vitesses radiales de l'étoile *β Aurigae*," No. 3916.

stars within each group is $19^h.1$, while each group completes a revolution about the center of gravity of the system in $3^d\ 23^h.5$. The ratio of the masses of the groups is nearly 1, and the center of gravity of the system has a radial velocity of —16 km. Finally it is stated in the article that conjunction occurred on February 3, 1903, at 10^h Pulkowa M. T., and that on February 4 the component on the side toward red of the *Mg* line at λ4481 was

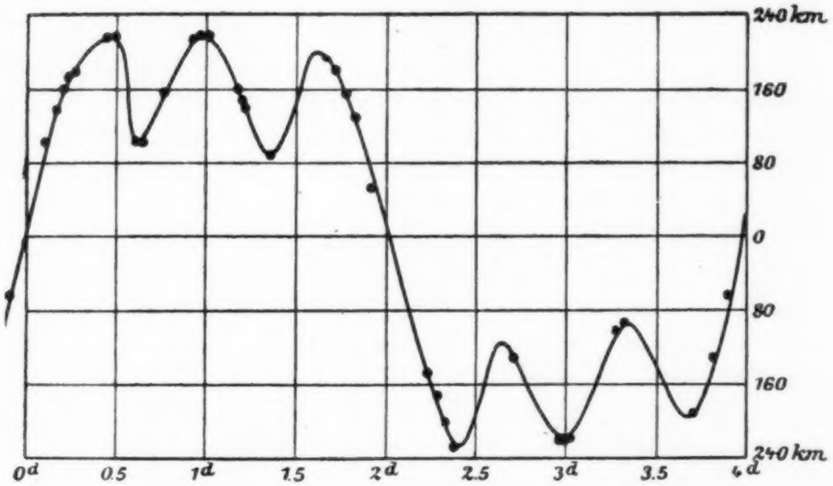


Fig. 1. — Velocity-Curve according to Tikhoff.

the stronger. I have previously observed such duplications of the components of the single lines in the spectrum of ζ *Ursae Majoris*, but it is entirely incomprehensible to me how they should cause precisely similar depressions in the velocity-curve at the two points of maximum, corresponding to a change of velocity of about 90 km.

Although I had to regard Mr. Tikhoff's conclusions from his observations as somewhat premature and certainly depending upon a very insecure foundation, I nevertheless felt that an immediate further examination of the relations in this binary system was a pressing necessity, and accordingly we began at once to obtain spectrograms of β *Aurigae*.

RECENT OBSERVATIONS AT THE POTSDAM OBSERVATORY.

The incredibly bad atmospheric conditions during last December defeated the earnest efforts of Drs. Eberhard and Ludendorff to quickly obtain the necessary data. The scattered observations did not permit any certainty as to the phase of the binary, and at the beginning of the year it could only be seen definitely that the observations so far obtained could not in any way be made to agree with Pickering's period. This somewhat disturbing condition was not broken until January 27, 1904 (the first and only continuously clear night from the middle of December until now), when it was possible to secure seventeen successive observations, and two observations on the next evening. Thus the time of the superposition of the spectra could be established with extreme accuracy, and from now on the observations could be represented by a period entirely different from that previously assumed. Later observations further confirm the fact that the period derived from the Cambridge observations was entirely incorrect. A period of 3^d960 furnished, first a satisfactory connection with Tikhoff's epoch of conjunction given above, and then with Hartmann's four plates in September 1901, and finally, with a small alteration of the period, with the epoch of superposition of spectra on January 1, 1891, that I had given. I further succeeded with a period

$$P = 3^{d}.9599 = 3^{d}\ 23^{h}\ 2^{m}\ 16^{s}$$

not only in representing all the earlier Potsdam observations, but also in recognizing the excellence of Tikhoff's measures, which neatly fitted a sine curve, and thus all the anomalies found by Tikhoff were made to disappear. The computations were all made by Dr. Schweydar with the formula

$$v = 222 \sin\left(\frac{t - t_0}{P} \times 360^{\circ}\right) ,$$

where P is the period just given, 222 km represents the maximum separation of the lines, and t_0 is taken as 1904, January 27.750, Central European Time.

Tikhoff's observations fit this formula as perfectly as is possible in view of the uncertainty of measurement of the lines in

such spectra, which are not easy to set upon; and the beautiful set of observed data furnished by him makes it possible definitively to conclude the investigations on *β Aurigae* at this time, in so far as they refer to the determination of the orbit, the masses, and the radial velocity of the system.

Further investigations would be desirable to clear up the matter of the continuous change in the appearance of the lines in the spectra of such binaries, but these should be made only under the most favorable conditions and with very high dispersion. I shall take up this point more in particular later, but will now give here the results of my measures on the plates taken with Spectograph IV attached to the 33cm refractor by Drs. Eberhard and Ludendorff, working either together or in alternation.

No.	Date C. E. T.	*Mg*	*Ti*	Mean	Quality	Computed	C.-O.	Remarks
		km	km	km		km	km	
1	1903, Dec. 22.315	217	213	215	1–2	212	− 3	
2	24.230	210	226	218	1–2	217	− 1	
3	25.304	71	77	74	1	74	0	
4	27.275	56:	55:(½)	56:	½–1	71	+15	
5	28.291	200	190(½)	197	½–1	207	+10	Comp. *Mg*, *Ti* double
6	29.364	107	109(⅔)	108	½–1	106	− 2	
7	31.208	59		59	½–1	62	+ 3	
8	1904, Jan. 4.211	74	62(¼)	71	1	76	+ 5	
9	5.330	185	182	183	2	189	+ 6	Comp. *Hγ*, *Mg*, *Ti*
10	6.226	96:	75:(2)	82:	1	87	+ 5	double
11	10.274	131	131	117*	1	115	− 2	Comp. *Mg*, *Ti* double
12	.472	183		183	1	168	−15	
13	17.323	171	183	177	2	165	−12	Comp. *Hγ*, *Mg?*, *Ti*
14	.398	147	145	146	2	146	0	double
15	.519	133	125	129	1–2	111	−18	
16	19.457	134	137(½)	135	1	124	−11	
17	27.224	169	171	170	2	165	− 5	
18	.248	153		153	½–1	159	+ 6	Comp. *Mg*, very un-
19	.275	162		162	1	152	− 10	equal; *Hγ*, *Mg* double
20	.298	160		160	½	144	−16	
21	.323	151	153	152	1–2	139	−13	
22	.345	137		137	1	133	− 4	
23	.368	141	140	141	½–1	126	−15	
24	.390	124		124	½–1	120	− 4	2. Comp. *Mg* very
25	.412	127	130	128	1–2	114	−14	diffuse.
26	.435	115		115	½–1	106	− 9	Comp. *Mg* very un-
27	.457	111		111	½	100	−11	unequal
28	.482	109	94	102	½	92	−10	
29	.535	67	68	68	1	74	+ 6	
30	.557	60	60	60	1	67	+ 7	
31	.578	43	56	50	1	60	+10	
32	.603	67	59	63	1	51	−12	
33	.633	27	40	34	1	41	+ 7	
34	28.234	158		158	1	154	− 4	
35	.335	187		187	1	178	− 9	
36	30.240	160	156	158	1–2	161	+ 3	
37	.262	165	164	165	1–2	166	+ 1	
38	.282	164		164	½	171	+ 7	
39	Feb. 9.350	199		199	1	202	+ 3	

NOTES.—The third column contains the relative velocities as derived from the observations of the *Mg* line at λ 4481. The dispersion of the apparatus is such that

the displacement of one revolution of the screw (0.25 mm pitch) of the measuring machine corresponds to a velocity of 341.7 km. Column 4 contains the results of the measurements of a line very well defined on several plates, the wave-length of which I have determined to be 4549.69; since this is probably to be identified with the titanium line, the column has been headed *Ti*. In this region of the spectrum 1 rev. = 365.3 km. The measures on the *Ti* line are often of somewhat less weight than those on the *Mg* line, and the numbers in parentheses after certain values are the weights assigned in forming the mean given in column 5. A colon (:) indicates that the value is somewhat uncertain. The asterisk (*) at the eleventh plate denotes that in this case a very reliable measurement could be made of the separation of the double *Fe* line at λ 4326, which yielded a velocity of 102 km (2). Column 6 contains estimates as to the quality of the observations, the best plates being denoted by 2.

The deviations of the observations from the sine curve average from 7 to 8 km with the negative values in excess by — 3 km

No.	Date C. E. T.	Obs. Vel. Tikhoff	Comp. Vel.	C.–O.
		km	km	km
1	1902, Feb. 14.421	161	146	−15
2	15.388	160	172	+12
3	19.406	145	159	+14
4	26.381	173	166	− 7
5	26.410	180	173	− 7
6	27.379	142	145	+ 3
7	Mar. 4.401	172	184	+12
8	5.415	102	118	+16
9	11.448	84	89	+ 5
10	12.396	200	197	− 3
11	13.396	96	99	+ 3
12	24.407	228	214	−14
13	April 7.399	218	222	+ 4
14	7.427	218	222	+ 4
15	Nov. 15.517	191	193	+ 2
16	16.442	100	89	−11
17	17.438	198	202	+ 4
18	25.472	176	183	+ 7
19	26.454	131	124	− 7
20	Dec. 9.502	133	142	+ 9
21	11.445	154	152	− 2
22	14.417	155	162	+ 7
23	19.443	128	131	+ 3
24	1903, Jan. 18.371	65	59	− 6
25	19.406	216	218	+ 2
26	20.383	49	47	− 2
27	21.403	217	219	+ 2
28	23.408	219	220	+ 1
29	24.373	Single, broad	37	....
30	25.429	221	222	+ 1
31	31.398	218	222	+ 4
32	Feb. 3.403	Single, broad	8	....
33	10.375	217	221	+ 4
34	Mar. 11.296	102	95	− 7
35	21.379	147	148	+ 1
36	27.276	140	137	− 3

in the sense C.—O. As the larger values are mostly situated on the descending branch of the curve, they indicate that the descent of a curve drawn directly through the observed points is somewhat steeper than the ascent. If we wished to regard these slight deviations as real, we should be justified in concluding that the orbit was slightly elliptical. The probable error of the measures on one plate is $\pm$ 6km.

Tikhoff's measures, shown above (p. 372), fit the sine curve still more closely.

The deviations of the measured velocities from those represented by the curve average 6km, the negative and positive values nearly canceling (mean + 1 km). The probable error comes out as $\pm$ 5 km, so that the determinations are superior in accuracy to mine. This is accounted for by the facts that I limited my measures to the *Mg* line and the *Ti* line, while Mr. Tikhoff measured several lines on each plate, and that about half of the spectrograms used by him were made with a spectrograph of larger dimensions.

The epoch 1903, February 3, 8^h 59^m, given by Tikhoff for the superposition of the spectra, or for the conjunction of the components of the binary, is computed by the above formula to be February 3 9^h 6^m C. E. T.

I now return to the Potsdam observations of earlier years. The relative radial velocities computed from the above formula with the residuals in the sense C.—O. are as follows for the observations in 1901:

Sept. 23.514	220km,	− 5km	Sept. 25.558	215km,	+1km
24.553	49	+11	26.536	50	+4

On similarly computing the values for the dates in 1899 on which the spectrograms were obtained with the low-dispersion spectrograph D, we get these velocities:

March 5.5,	119km	March 14.46	196km
11.5,	101	15.43	111
12.43,	187	17.44	101
12.49,	198		

A comparison of the observations shows that they are not contradictory to the computation, which is also true for the

isolated observation made with the same instrument on 1896, May 7.456. The computed separation of the lines corresponds to a relative velocity of 216km.

Finally, the first observations made here for determining the radial velocity of stars with the spectrograph I designed in 1888 also fit the computed values as well as could be expected when we consider that these plates are in general less sharp, and that further the *Mg* line λ 4481 was situated outside the region of sharp definition of the camera objective. I have measured the plates again, but could not get any appreciably different *Auffassung*. On the plate of December 6, 1890, I was able with favorable illumination to see the separate components of the broad *Mg* line and to measure their separation. I give the observations here, together with the isolated observation taken in 1897 with the same instrument:

Date	Measure			Computed	C.–O.
	Former	New	Mean		
	km	km	km	km	km
1888, Nov. 14.424	188	181	185	146	−39
1889, Jan. 3.276	194	204	199	213	+14
1890, Nov. 22.401	30:	35	33	32	− 1
25.410	212	218	215	221	+ 6
26.428	(Single)	0:	0:	8	+ 8:
Dec. 14.338	(Single)	37	37	24	−13
21.281	205	207	206	220	+14
1897, Nov. 10.378	....	205	205	190	−15

NOTES.—The observations can be somewhat better fitted to the curve by increasing the period by three units of the fifth decimal, or by 3^s. We then get the following deviations of the separate observations in the sense C.–O.: −30 km, +17, −13, +7, +4, −1, +12, and −12 km. On further increasing the period the observations are not so well represented.

The time at which the spectral lines appeared single on January 1, 1891, is computed by the new formula to be $2^h\ 11^m$ C.E.T., while I formerly derived from the first seven observations, 1891, January 1, 3^h, G.M.T., or 4^h C.E.T.

I believe that after all these tests the correctness of the formula given may be considered as proved, and I regard the period as accurate within a few units of the fifth decimal or $\pm\ 5^s$, since the observations cover about 14 periods.

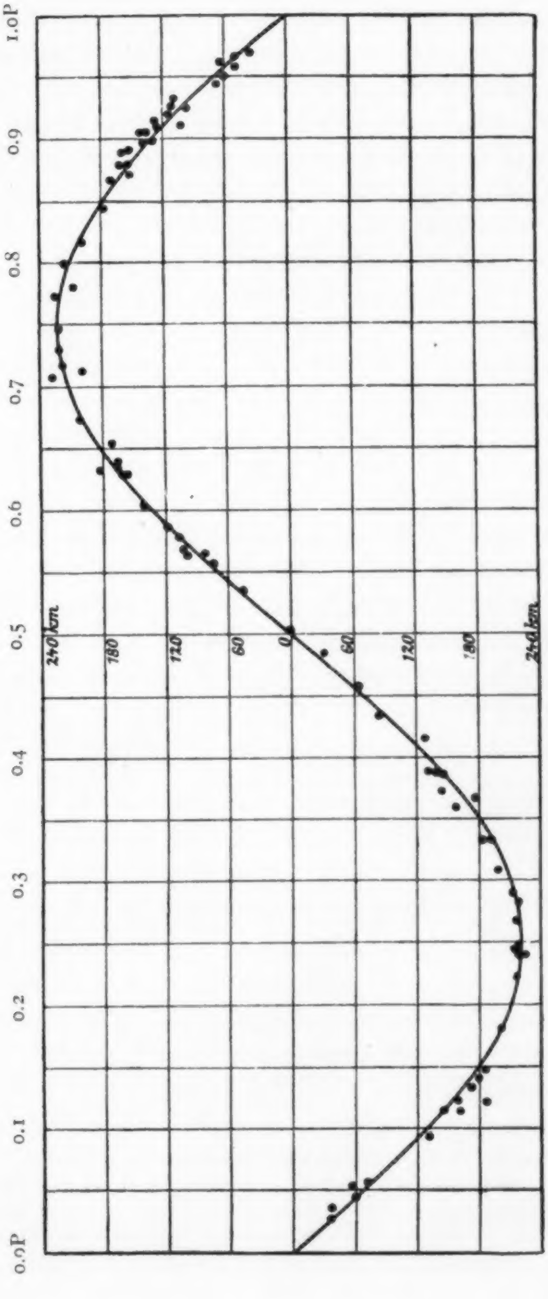


FIG. 2.—Velocity-Curve of β *Aurigae* according to Vogel.

The accompanying diagram shows that the eighty-five observations fall upon all parts of the curve, and that the deviations are only very slight from the sine curve and hence from a circular orbit. The eccentricity, if any should be established with certainty by later observations, would hardly exceed 0.05, so that Rambaut's early value of 0.156 is not confirmed.

On the assumption of a circular orbit, a relative velocity of the two bodies of 222 km, and the period derived above of $3^{d}.9599$, the result of the mass for the system is

$$m + m_1 = \frac{4.5 \odot}{\sin^3 i},$$

and the distance of the two bodies comes out as

$$a \sin i = 12 \text{ million km.}$$ [1]

(The discrepant value of 1.25⊙ for the mass of each of the components given by Miss Maury in the article referred to above is probably due to an error of the pen or of the type.)

As was shown above, and as is further confirmed by the following observations as to the radial velocity of the system, the masses of the two components of the system are not very different from each other.

RADIAL VELOCITY OF THE SYSTEM.

By referring the measures of the *Mg* line to the *Fe* comparison spectrum I have derived the motion of the system in the line of sight from the Potsdam observations of 1903 and 1904, and I find as the mean of the observations on thirty-five plates the value:

$$-21 \pm 1 \text{ km.}$$

[1] Since no variation has been thus far observed in the brightness of *β Aurigae*, so that a partial occultation of the bodies does not occur, the maximum value for the angle i included between the line of sight and the perpendicular to the plane of the orbit can be computed if we make further assumptions as to the diameters of the two bodies. In view of the early stage of development of stars of class I*a*2, we may doubtless assume that their density is less than that of the Sun. If we take the diameters of the components of *β Aurigae* to be twice that of the Sun, we get $i = 77°$, and then $a = 12{,}400{,}000$ km, and $m + m_1 = 4.9\odot$. For $i = 60$ these values increase decidedly, so that a becomes in round numbers 14,000,000 km, and the masses become $6.9\odot$.

This value agrees well with that of -19 found by M. Deslandres in 1892, with that of -18 given by the four Potsdam plates of 1901, and with that of -16 km determined by Tikhoff. In deriving the velocity of the system the displacement of the center of the separated *Mg* lines is obtained by reference to the *Fe* lines, and if the center of gravity did not fall very nearly midway between the two bodies, variations in the values thus obtained for the amount of displacement would have to appear as a result of the motion of the system. The variations among the separate values are not greater, however, than would be expected for the difficultly observable *Mg* line.

The observations in one half of the orbit, between the points where the lines are superposed, give a mean value for the velocity of the system of -19.4 km, and for the other half of the orbit of -22.7 km.

The near equality in the masses of the two component systems can be further confirmed by the direct computation of the velocity of the separate bodies relative to the Sun from the displacement of the *Mg* lines as compared with the lines of the comparison spectrum. A computation and graphic representation by Dr. Schweydar shows that one and the same sine curve represents very well the velocities found for each body, on the assumption of a maximum velocity of 111 km.

ON THE PERIODIC CHANGES IN THE APPEARANCE OF THE LINES.

As I have stated above, I noticed during the earliest observations that one component of the *Mg* line appeared broader, somewhat more diffuse, and probably also somewhat stronger than the other, and that a change took place in that first the stronger and then the fainter component fell further toward the red. This observation suggested the idea that the spectrum of one of the bodies was somewhat more intense than that of the other, and that the change stood in relation to the position of the bodies in their orbit.

The few observations then available were not sufficient to make the matter certain, but as I had no reason for doubting the correctness of this assumption, I characterized the appear-

ance of the spectrum by the statement: "On January 2, 1891, the more refrangible component of the *Mg* lines is the stronger." (See above.)

Mr. Tikhoff must have taken a quite similar point of view, since he states, in an expression analogous to that I made twelve years ago: "On February 4, 1903, the strongest component of the *Mg* line is the least refrangible." Unfortunately no remarks are added to his observations as to the relative intensity of the components; otherwise it would have been possible for me to decide, on the basis of the correct period, whether or not a change of the intensities actually occurs after each conjunction. Such a change must occur if the lines in the spectrum of one of the bodies are invariably stronger than in the other, but it would not occur if the change were purely accidental.

I have not been able to prove the fact of any regular change dependent upon the orbital position of the bodies; but, on the contrary, have been convinced by the recent observations, particularly by the continuous series of plates made on the night of January 27–28 of this year, that the change occurs wholly irregularly.

A change in the relative intensity of the components of the *Mg* lines also occurs in the case of ζ *Ursae Majoris*, but it has been just as impossible for me, as in the case of β *Aurigae*, to discover a relation with the phase at which the bodies composing the binary system are situated at the time.

In her article, which I mentioned at the beginning of this paper, Miss Maury made a summary by counting the plates in one year on which the component of K toward the red was the stronger, and obtaining the number of those for which the opposite was true, and the number of those in which both components appeared equally strong. She finds a change in the relative intensity on the plates, which cover a period of nine years, to the effect that a reversal occurs every year; that is, that the relative intensities of the components of K behave during one year in just the opposite manner to that of the preceding year.

Now it is easy to see that such statistics cannot lead to any

useful results unless they are made out in connection with a curve representing the observations. For, assuming that a change actually occurs after every conjunction, it might chance that in one year the greater number of the plates were photographed at a time when the stars were situated in the first half of the orbit between two conjunctions, but in the next year, in the second half of the orbit. The only thing of interest that can be taken from the table is the number of cases in which the components appear equally strong, which on the average constitute only 17 per cent. of all the observations.

The magnitude of the variations of intensity of the *Mg* line, to which my observations principally refer, is often very considerable. On some plates the one component is sharp, very distinct, and well defined, while the other is, on the contrary, very broad, diffuse, and so faint that its position can be measured only with difficulty. Sometimes one line will appear double, and sometimes both; they then consist either of a broad and a very narrow line, or of two equally broad lines, whose separation corresponds to a relative velocity of 40 to 50 km. The *Mg* and *Ti* lines often agree entirely, but more frequently they are wholly different. The hydrogen line $H\gamma$ appears distinctly quadruple on some plates, and there sometimes occur in the spectrum new lines, single, and often quite sharp, for which no components can be found, while the *Mg* lines are separated.

These are all phenomena which I have already also observed in the spectrum of ζ *Ursae Majoris*. I quote here a passage referring to this matter from my second paper[1] on that star:

I have already spoken in my first paper on the observations of *Mizar* as to the variation in appearance of the components of the *Mg* line on different plates. The further observations have not made it possible to decide that the variations bear a relation to the period.

It is seldom that the components of the *Mg* line are equal in respect to intensity and width, and commonly the more refrangible of the components is the broader. No change in the appearance can be definitely proved after the superposition of the spectra. Some of the recent observations show both

[1] First paper, *Berlin Sitzungsberichte*, 1901, **24**, 534 *et seq*., ASTROPHYSICAL JOURNAL, **13**, 324–328, 1901; second paper, "Weitere Untersuchungen über das spectroscopische Doppelsternsystem *Mizar*," *Archives Néerlandaises*, Haarlem, 1901, 661 *et seq*.

components to be themselves double, in which case the lines of the two pairs are very sharp and narrow. It does not seem possible to regard these inequalities as due to accidental changes in the grain of the photographic film, since similar variations are occasionally exhibited in the case of some of the iron lines, although this is of less certainty on account of the faintness of the lines. The assumption does not seem to me, however, to be unlikely that the great variation in the separation of the two bodies during their orbital motion (from 16 to 51 million kilometers) may cause mutual disturbances in the atmospheres of the bodies which at times might produce phenomena of reversals or of broadening of the lines.

Although it seems justifiable to assume the existence of such disturbances in the atmospheres in the case of *Mizar* with its strongly elliptical orbit ($e = 0.502$), in the present case of an almost circular orbit, there is no basis for such an assumption.

The view expressed by Tikhoff that each of the components is also a double star cannot be directly denied, but in my opinion it receives no support from the similar behavior of the lines of *Mizar*. I would therefore call attention to the following reasoning.

The spectra of class I*a*2 show only a greater or less number of quite faint lines aside from the broad lines of hydrogen, calcium, magnesium, iron, and titanium. The continuous spectrum of *β Aurigae* seems at the time of perfect or almost perfect superposition of the two spectra to be crossed by a very large number of fine lines, so that the continuous spectrum gets the appearance of a fine parallel structure irresolvable at some points. When two such spectra are brought one upon the other by the displacement, the lines of the one spectrum are projected upon the by no means uniform spectral background, and thus lines which would be scarcely recognizable in a single spectrum can and must suddenly appear to be greatly strengthened; but others will be very much weakened if they fall upon one of the brighter portions of the superposed spectrum.[1] I am of the opinion that this may

[1] I was led to this opinion by the results obtained on using the method suggested by Mr. Bélopolsky, of Pulkowa, for making very faint lines in spectra better visible. The method consists in laying two spectrograms of the same object over each other so that the principal lines coincide. Faint lines then come out very clearly, and if a photograph is made of these superposed plates, the lines of this new spectrogram can be still further strengthened by placing over it one of the first plates.

possibly also explain the occasional duplication, and the change of the relative intensity or of the sharpness of the broad separated *Mg* and *Ti* lines or of the K line. The additional circumstance enters that with the possible exception of calcium, the absorption is not very strong in the atmosphere of bodies of class I*a*2, so that in general the superposition of two spectra will cause the lines to be brightened up to some extent, if the spectra are not in perfect coincidence. It is on account of this that the success of spectrograms of such spectra is so very dependent upon the correct exposure. There can be no doubt, further, that the structure of the photographic film here plays a much more important part than in the case of plates of spectra which are not superposed.

Only spectrograms obtained with very high dispersion on plates of the finest possible grain can be employed for establishing the cause of these phenomena. It will be necessary to secure frequent plates at short intervals and to compare the variations of the *Mg* line at $\lambda 4481$ with those of other lines.

POTSDAM, March 1904.

LINE OF SIGHT CONSTANTS FOR SOME STARS OF THE *ORION* TYPE.

By Emily Elisabeth Dobbin.

The line-of-sight constants for the following 112 stars of the *Orion* type were computed for the reduction of observations made with the Bruce spectrograph at the Yerkes Observatory, upon which the writer has been engaged during recent months. The formulæ employed by Dr. Frank Schlesinger in his "Line of Sight Constants for the Principal Stars"[1] were used, and the arrangement of the results is the same, with the minor exceptions that the latitude of the star is omitted and the right ascension and declination are added. The stars are taken from the regular observing program made out by Professor Frost from the lists of Vogel and Wilsing,[2] and of Miss Maury and Miss Cannon.[3] But those stars are omitted which were already included in Schlesinger's list. The magnitudes of the stars are for the most part taken from the *Harvard Photometry*.

In bringing the positions of the stars to the epoch 1900, no correction for proper motion was made. The constants for about forty of the stars were first computed by Mr. H. A. Fisher, Jr., but these have been repeated. All the results here collected were derived twice independently.

For the sake of completeness, the formulæ are repeated here. The correction x, to compensate for the orbital velocity of the Earth, is

$$x = b \sin(\odot - \lambda) + c \ .$$

Of course, λ must be corrected for the precession since 1900 to the beginning of the year for which it is required, by the addition of $50''$ per year. λ, b, and c were derived from the formulæ

$$\tan\lambda = [9.96255] \tan\alpha + [9.59987] \sec\alpha \tan\delta \ ,$$
$$b = [1.47371] \sec\lambda \cos\alpha \cos\delta \ ,$$
$$c = [8.224]\, b \sin(281^\circ\, 20' - \lambda) \ .$$

[1] Astrophysical Journal, **10**, 1, 1899.

[2] *Publicationen des Astrophysikalischen Observatoriums zu Potsdam*, **12**, 1–73, 1899.

[3] *Annals of Harvard College Observatory*, **28**, 1897 and 1901.

Star	Mag.	R. A.	Dec.	λ (1900)	log b	c
49 *Cassiopeiae*	5.0	0h 30m 34s	+53° 37′.0	33° 44′.8	1.3232	−0.33
ξ *Cassiopeiae*	4.9	0 36 29	+49 57.9	32 05.4	1.3486	−0.35
68 *Cassiopeiae*	5.5	0 38 53	+47 19.0	30 45.0	1.3644	−0.37
ν *Andromedae*	4.4	0 44 18	+40 32.0	27 45.6	1.3995	−0.40
146 *Cassiopeiae*	5.5	0 50 45	+59 49.3	42 14.5	1.2949	−0.28
α *Sculptoris*	4.1	0 53 47	−29 53.9	359 05.2	1.3997	−0.41
g *Persei*	5.0	1 55 38	+54 00.3	48 33.2	1.3643	−0.31
35 *Arietis*	4.5	2 37 35	+27 16.9	45 32.4	1.4652	−0.40
B. D. 51°665 *Persei*	5.2	2 53 44	+51 57.3	57 29.2	1.3942	−0.29
1 Hev. *Camelopardi*	4.8	3 11 11	+65 17.2	66 29.4	1.3213	−0.20
29 *Persei*	5.3	3 11 30	+49 51.4	59 47.8	1.4080	−0.28
τ *Arietis*	5.2	3 15 27	+20 47.2	51 59.9	1.4733	−0.38
B. D. 48°899 *Persei*	5.2	3 16 08	+48 51.4	60 16.4	1.4132	−0.28
2 Hev. *Camelopardi*	4.2	3 20 58	+59 35.6	65 11.3	1.3610	−0.23
3 Hev. *Camelopardi*	4.7	3 21 55	+58 32.0	64 53.6	1.3674	−0.23
34 *Persei*	4.8	3 22 13	+49 09.8	61 28.4	1.4132	−0.28
τ5 *Eridani*	4.2	3 29 22	−21 58.1	42 47.9	1.3614	−0.33
40 *Persei*	5.0	3 36 02	+33 38.7	59 44.2	1.4608	−0.32
q *Tauri*	4.3	3 39 15	+24 09.2	58 10.1	1.4724	−0.34
20 *Tauri*	5.0	3 39 52	+24 03.4	58 17.0	1.4724	−0.34
e *Tauri*	5.0	3 42 47	+10 50.2	55 57.0	1.4687	−0.35
τ8 *Eridani*	4.7	3 49 27	−24 54.4	47 27.6	1.3331	−0.29
B. D. 34°768 *Persei*	5.5	3 50 02	+34 47.4	62 54.7	1.4599	−0.30
40 *Tauri*	5.3	3 58 26	+ 5 09.6	58 33.2	1.4586	−0.33
μ *Tauri*	4.3	4 10 06	+ 8 38.5	62 11.0	1.4638	−0.31
d *Persei*	4.9	4 14 19	+46 15.6	70 13.3	1.4324	−0.23
τ *Tauri*	4.3	4 36 14	+22 45.9	70 45.4	1.4737	−0.25
μ *Eridani*	4.0	4 40 30	− 3 26.3	67 56.3	1.4296	−0.25
9 *Camelopardi*	4.4	4 44 06	+66 10.4	79 35.0	1.3349	−0.13
π4 *Orionis*	4.0	4 45 53	+ 5 26.1	70 42.2	1.4548	−0.24
ψ *Eridani*	4.8	4 56 35	− 7 19.1	71 48.6	1.4122	−0.21
B. D. 34°980 *Aurigae*	5.9	5 09 42	+34 11.9	79 25.2	1.4653	−0.18
τ *Orionis*	3.6	5 12 45	− 6 57.2	76 27.0	1.4119	−0.18
o 22 *Orionis*	4.0	5 16 39	− 0 28.9	78 10.4	1.4362	−0.18
25 *Orionis*	4.8	5 19 33	+ 1 45.3	79 08.6	1.4429	−0.18
ψ *Orionis*	4.7	5 21 36	+ 3 00.6	79 47.1	1.4464	−0.17
A Orionis	4.0	5 25 26	+ 5 52.4	80 59.6	1.4535	−0.16
χ *Aurigae*	5.0	5 26 13	+32 07.1	82 46.0	1.4685	−0.16
v 36 *Orionis*	4.5	5 27 06	− 7 22.4	80 31.0	1.4088	−0.15
35 *Orionis*	5.7	5 28 13	+14 14.2	82 12.2	1.4683	−0.16
φ1 *Orionis*	4.6	5 29 20	+ 9 25.3	82 12.6	1.4609	−0.16
S. D.−6°1233 *Orionis*	4.5	5 30 [illegible]	− 6 04.1	81 29.1	1.4143	−0.15
Bond 619 *Orionis*	7	5 30 21	− 5 27.2	81 34.9	1.4168	−0.15
Bond 624 *Orionis*	8	5 30 22	− 5 27.1	81 35.0	1.4168	−0.15
Bond 640 *Orionis*	7	5 30 23	− 5 27.2	81 35.3	1.4168	−0.15
θ1 *Orionis*	4.6	5 30 22	− 5 27.3	81 35.1	1.4166	−0.15
c1 *Orionis*	4.7	5 30 27	− 4 54.2	81 38.8	1.4191	−0.15
θ2 *Orionis*	5.3	5 30 28	− 5 28.9	81 36.8	1.4167	−0.15
ω *Orionis*	4.5	5 33 54	+ 4 03.9	83 06.4	1.4488	−0.15
S. D.−3°1167 *Orionis*	6.0	5 34 32	− 3 37.2	82 52.3	1.4239	−0.14
S. D.−1°1004 *Orionis*	4.9	5 35 46	− 1 10.9	83 20.5	1.4327	−0.14
57 *Orionis*	5.8	5 49 02	+19 43.8	87 24.7	1.4728	−0.12
139 *Tauri*	5.0	5 51 47	+25 56.4	88 09.2	1.3731	−0.09
64 *Orionis*	5.1	5 57 32	+19 41.6	89 25.1	1.4728	−0.10
χ2 *Orionis*	4.8	5 57 59	+20 08.4	89 31.5	1.4729	−0.10
ν *Orionis*	4.7	6 01 52	+14 46.8	90 27.3	1.4688	−0.09
ξ *Orionis*	4.4	6 06 15	+14 13.9	91 32.2	1.4680	−0.08
f1 *Orionis*	4.8	6 06 17	+16 09.2	91 31.3	1.4702	−0.08
S. D.−6°1446 *Monocerotis*	5.1	6 07 00	− 6 31.6	92 00.4	1.4114	−0.07
ζ *Canis Majoris*	3.0	6 16 28	−30 01.2	95 59.1	1.2493	−0.03

Star	Mag.	R. A.	Dec.	λ (1900)	log b	c
10 *Monocerotis*	4.9	6 23 01	− 4 42.0	96 30.0	1.4196	−0.04
ν *Geminorum*	4.2	6 23 02	+20 16.5	95 24.4	1.4731	−0.05
11 *Monocerotis* seq.	5.5	6 23 58	− 6 58.2	96 53.6	1.4100	−0.03
ξ¹ *Canis Majoris*	4.4	6 27 41	−23 20.8	99 15.8	1.3109	−0.01
Lal. 12587	5.9	6 28 33	− 1 08.6	97 50.5	1.4331	−0.03
42 *Camelopardi*	5.1	6 40 32	+67 41.0	95 22.0	1.3276	−0.04
15 *Canis Majoris*	4.6	6 49 14	−20 06.0	105 51.0	1.3387	+0.03
ο² *Canis Majoris*	3.0	6 58 51	−23 41.2	109 36.8	1.3144	+0.05
γ *Canis Majoris*	4.2	6 59 14	−15 29.1	108 13.0	1.3702	+0.05
ω *Canis Majoris*	3.7	7 10 45	−26 35.5	114 14.5	1.2944	+0.07
29 *Canis Majoris*	4.8	7 14 30	−24 22.5	114 52.3	1.3137	+0.08
16 *Argus*	4.2	8 04 34	−18 57.1	128 34.2	1.3682	+0.18
η *Hydrae*	4.2	8 38 00	+ 3 45.5	130 54.6	1.4601	+0.24
κ 76 *Cancri*	5.3	9 02 20	+11 04.2	134 46.4	1.4716	+0.27
S. D.−8°.4010 *Librae*	5.0	15 29 02	− 8 50.8	232 08.5	1.4673	+0.37
τ *Librae*	3.9	15 32 31	−29 26.9	237 57.3	1.4670	+0.34
π *Scorpii*	3.1	15 32 48	−25 49.6	241 32.6	1.4717	+0.32
ω¹ *Scorpii*	4.1	16 00 57	−20 23.9	242 16.4	1.4737	+0.31
σ *Scorpii*	3.0	16 15 06	−25 21.2	240 24.2	1.4726	+0.28
τ *Scorpii*	2.9	16 29 39	−28 00.5	250 03.6	1.4712	+0.26
u 68 *Herculis*	5.0	17 13 40	+33 12.5	252 31.3	1.2217	+0.13
66 *Ophiuchi*	4.8	17 55 19	+ 4 22.4	268 40.5	1.4194	+0.10
96 *Herculis*	5.1	17 58 07	+20 50.0	269 23.0	1.3285	+0.07
102 *Herculis*	3.5	18 04 29	+20 48.0	271 27.6	1.3287	+0.06
φ *Sagittarii*	3.3	18 39 24	−27 05.6	278 47.0	1.4727	+0.02
δ¹ *Lyrae*	5.3	18 50 14	+36 50.8	290 00.4	1.1801	−0.04
18 *Aquilae*	5.0	19 02 16	+10 55.0	288 23.7	1.3954	−0.05
η *Lyrae*	4.8	19 10 21	+38 58.5	298 40.6	1.1635	−0.07
2 *Cygni*	4.8	19 20 11	+29 25.5	298 16.4	1.2733	−0.09
8 *Cygni*	4.8	19 28 03	+34 14.4	302 53.4	1.2301	−0.10
ι *Aquilae*	4.3	19 31 33	− 1 30.5	294 26.6	1.4466	−0.11
Lal. 38896	4.8	20 11 02	+25 17.2	312 50.4	1.3307	−0.19
P Cygni	4.9	20 14 06	+37 43.3	309 36.1	1.3096	−0.16
ω¹ *Cygni*	4.9	20 26 58	+48 36.9	334 38.7	1.1148	−0.18
57 *Cygni*	4.6	20 49 43	+44 00.5	336 32.8	1.1971	−0.22
G Cephei	5.7	21 09 16	+59 34.5	355 39.9	1.0458	−0.18
v 66 *Cygni*	4.4	21 13 48	+34 28.6	335 52.4	1.3037	−0.27
A Cygni	5.1	21 14 44	+43 31.5	343 08.1	1.2289	−0.25
70 *Cygni*	5.2	21 23 17	+36 40.9	339 56.0	1.2944	−0.28
13 Hev. *Cephei*	5.7	21 35 51	+57 02.2	354 46.2	1.1190	−0.21
π¹ *Cygni*	4.7	21 38 33	+50 44.0	356 54.2	1.1887	−0.25
π² *Cygni*	4.3	21 43 06	+48 50.8	355 48.4	1.2106	−0.26
16 *Pegasi*	5.2	21 48 31	+25 27.3	20 10.0	1.3811	−0.40
2 *Lacertae*	4.5	22 16 54	+46 01.9	0 52.2	1.2698	−0.31
4 *Lacertae*	4.6	22 20 28	+48 58.1	4 29.6	1.2499	−0.30
6 *Lacertae*	4.5	22 26 10	+42 36.6	0 38.4	1.3031	−0.33
10 *Lacertae*	4.9	22 34 46	+38 31.8	358 59.4	1.3364	−0.36
β *Piscium*	4.3	22 58 47	+ 3 16.9	347 11.4	1.4683	−0.45
1 *Cassiopeiae*	5.0	23 02 23	+58 52.8	23 59.3	1.2124	−0.27
1 Hev. *Cassiopeiae*	5.0	23 25 25	+57 59.9	26 46.8	1.2433	−0.28
λ *Piscium*	4.4	23 36 57	+ 1 13.8	355 10.7	1.4729	−0.48
σ *Cassiopeiae*	5.0	23 53 56	+55 11.9	28 44.7	1.2871	−0.31

YERKES OBSERVATORY,
May 5, 1904.

Minor Contributions and Notes.

AN EXPEDITION FOR SOLAR RESEARCH.

With the aid of a grant of $10,000 from the Carnegie Institution, for use during the current year, the Yerkes Observatory has sent an expedition to Mount Wilson (5,886 feet) near Pasadena, California, for the purpose of making special investigations of the Sun. The principal instrument to be erected on the mountain is the Snow horizontal telescope, recently constructed in the instrument and optical shops of the Yerkes Observatory. This telescope is a cœlostat reflector, the cœlostat mirror having a diameter of 30 inches. A second plane mirror, 24 inches in diameter, reflects the beam from the cœlostat north to either one of two concave mirrors, each of 24 inches aperture. One of these concave mirrors, of about 60 feet focal length, is to be used in conjunction with a solar spectrograph of 5 inches aperture and 13 feet focal length; a spectroheliograph of 7 inches aperture, resembling the Rumford spectroheliograph of the Yerkes Observatory; and a stellar spectrograph provided with a large concave grating, and mounted in a constant temperature laboratory. It is hoped that it will be possible with this stellar spectrograph to photograph the spectra of a few of the brightest stars. For fainter stars, the spectrograph is to be provided with several prisms, for use singly or in combination.

The second concave mirror of the cœlostat reflector is designed to give a large focal image of the Sun, especially adapted for investigations with a powerful spectroheliograph, and for spectroscopic studies of Sun-spots and other solar phenomena. The focal length of this mirror is about 145 feet, so that it will give a solar image about 16 inches in diameter. The spectroheliograph is to be of 7 inches aperture and 30 feet focal length. For the present, until a suitable grating can be obtained, the dispersive train of this instrument will consist of three prisms of 45° refracting angle, used in conjunction with a plane mirror, so as to give a total deviation of 180°. The motion of the solar image, of which a zone about 4 inches wide can be photographed with the spectroheliograph, will be produced by rotating the concave mirror about a vertical axis by means of a driving-clock. A second

driving-clock, controlled electrically so as to be synchronous with the first driving-clock, will cause the photographic plate to move behind the second slits. Three slits will be provided at this point, so as to permit photographs to be taken simultaneously through as many different lines of the spectra. It is hoped that this spectroheliograph will prove to be well suited for use with some of the narrower dark lines of the solar spectrum.

The work is to be under the immediate direction of Professor George E. Hale, Director of the Yerkes Observatory. During his absence Professor Edwin B. Frost will be in immediate charge of the Yerkes Observatory, with the title of Acting Director. Professor Frost will also be the managing editor of the ASTROPHYSICAL JOURNAL. Mr. Ferdinand Ellerman and Mr. Walter S. Adams, of the Observatory staff, will be associated with Professor Hale in the work at Mount Wilson.

Correspondents are requested to send all letters, books, or pamphlets intended for Messrs. Hale, Ellerman, or Adams to 678 St. John Avenue, Pasadena, California.

Reviews

Die Bilderzeugung in optischen Instrumenten vom Standpunkte der geometrischen Optik. Herausgegeben von M. von Rohr. Berlin: Julius Springer. 1904.

The appearance of the names of Czapski, König, Löwe, and others of the Carl Zeiss optical works in connection with a book edited by the author of the *Theorie des photographischen Objectivs* must necessarily mark an epoch in the theory of optical instruments. The work can, in fact, be called nothing less than encyclopædic in its range and completeness, and from the standpoint both of the student of geometrical optics and of the practical optician will prove of extreme value. The difficulty of finding a satisfactory treatment of the theory of the various aberrations when applied to lens construction is one which is familiar to all who have dealt with optical instruments, and it is to them that such chapters as that of König and von Rohr on spherical aberration, and those of König on chromatic aberration, and on the computation of optical systems, will especially appeal.

It is, of course, impossible to attempt to cover the contents of a work of this character within the limits of a brief review, and in the following we shall give only a general outline, with occasional reference to some of the more striking features. The choice of the latter, however, is by no means easy in the present case.

The first four chapters of the book are devoted to the consideration of the fundamental properties of geometrical rays and pencils when reflected or refracted at the surface of different media. The first chapter introduces the conception of the geometrical ray, and the general theorems of reflection and refraction, and under these, in turn, are discussed the important principles of the shortest path, or its modification, the shortest time, the law of Malus, and the mathematically valuable, although practically somewhat unrealizable characteristic function of Hamilton. The chapter closes with the definition of the cardinal terms in use with an optical system. The treatment throughout is thoroughly general and forms an admirable basis for the succeeding chapter, in which the course of the geometrical ray is followed through the optical system. The formulæ are here derived first for the simplest

case of axial rays, and are then extended to meridional rays, and finally to rays with finite inclination to both of the axial planes.

In the third and fourth chapters the theory of the formation of optical images is considered. The former derives the general laws connecting object and image, while the latter discusses the cases which arise for different forms of the reflecting or refracting surfaces. The separation between telescopic images and those for objects of finite distance is made early in the treatment, and the relations deduced between them form one of the most interesting features of this part of the book. At the close of the fourth chapter are given a number of historical notices in regard to the material considered, an especially valuable bibliography being added under the subject of astigmatism.

With the the fifth chapter begins an extraordinarily complete and lucid discussion of the theory of spherical aberration, which can scarcely become other than a classic on the subject. Abbe's method of invariants is applied to the derivation of the formulæ for Seidel's aberrations, and the developments are carried as far as to the third power of the inclination in the case of non-axial rays forming a pencil of finite angular aperture. As is stated in the preface, a considerable part of this development is here carried out for the first time. The different aberrations are treated separately, a process which assists remarkably in giving clearness to this complex subject.

The chapter on chromatic aberration is comparatively brief. After a consideration of the size of the circles of aberration, and Gauss's method for determining the amount of chromatic variation for a given system in any case from a knowledge of its amount in a single instance, the author treats the different lens combinations in detail. A short but valuable section on the variations of spherical aberration with wave-length closes the discussion.

The seventh chapter, on the computation of optical systems on the basis of the theory of the aberrations, is of especial value as applying the material developed in the two previous chapters. The conditions for the elimination of each aberration are set out in detail, and the summary of formulæ under each separate case is of extreme practical value. At the close of the chapter two very interesting sections are appended; the first on the correction of outstanding aberration through the introduction of slight changes into the radii of curvature of the lenses; the second on the relation of eyepiece to objective in an optical system, and on the relative aberrations of similar systems in which the linear dimensions have an integral ratio.

Lack of space precludes a detailed summary of the contents of the remainder of the book. A chapter on prisms and prism-systems by Löwe is followed by a valuable discussion by von Rohr of the eye in its relation to optical instruments. The last chapter, also by von Rohr, is an application of photometric principles to optical systems, and contains many distinctly novel results. The book closes with a table of the symbols used in the course of the various developments, which will be found of decided convenience for reference.

The purely geometrical character of the treatment throughout the entire book is emphasized in the preface, and should be carefully borne in mind by the reader, who in many cases would do well to have a parallel course of reading in some treatise on physical optics. In conclusion attention should be called to the marked character of unity running through the work, which, in view of the great range of material, and the diversity of authorship, can be called nothing less than remarkable, and reflects great credit upon the editor, Dr. von Rohr. Finally, no review would be complete without some reference to the admirable press-work of the volume, and to the absence of typographical errors in a series of developments in which the extremely complicated system of notation would make such errors readily excusable.

W. S. A.

Cours élémentaire d'astronomie et de navigation. Par P. Constan, professeur d'hydrographie de la marine. Première Partie, Astronomie (pp. vi+264), 1903. Deuxième Partie (pp. 296), 1904. Paris: Gauthier-Villars.

These two volumes, published at the request of Professor Constan's former pupils, contain everything that, in the author's opinion, need be known by a modern navigator. They compare very favorably with similar works in our own language intended for the same class of students. The present work is eminently practical, without slighting the necessary theory; the demonstrations are straightforward and simple, and the illustrations are models of clearness.

The author has sought to relieve the subject of some of the dryness it must inevitably have for the majority of students, by introducing occasional historical references. These, however, show a rather amusing bias toward the author's own countrymen. For example, the compensating pendulum is attributed to Leroy instead of Harrison;

the heliometer to Bouguer alone, instead of to Dollond and Savery as well; and the discovery of Neptune to Leverrier alone. The same bias is shown in the choice of numerical data: the author recommends Caillet's tables for refraction; he cites Faye's elements of the Earth's size and shape, and only Fizeau's and Cornu's determinations of the velocity of light.

F. S.

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VOLUME XIX NUMBER 5

THE ASTROPHYSICAL JOURNAL

An International Review of Spectroscopy and Astronomical Physics

JUNE 1904

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THE

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AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOL. XIX — JUNE 1904 — NO. 5

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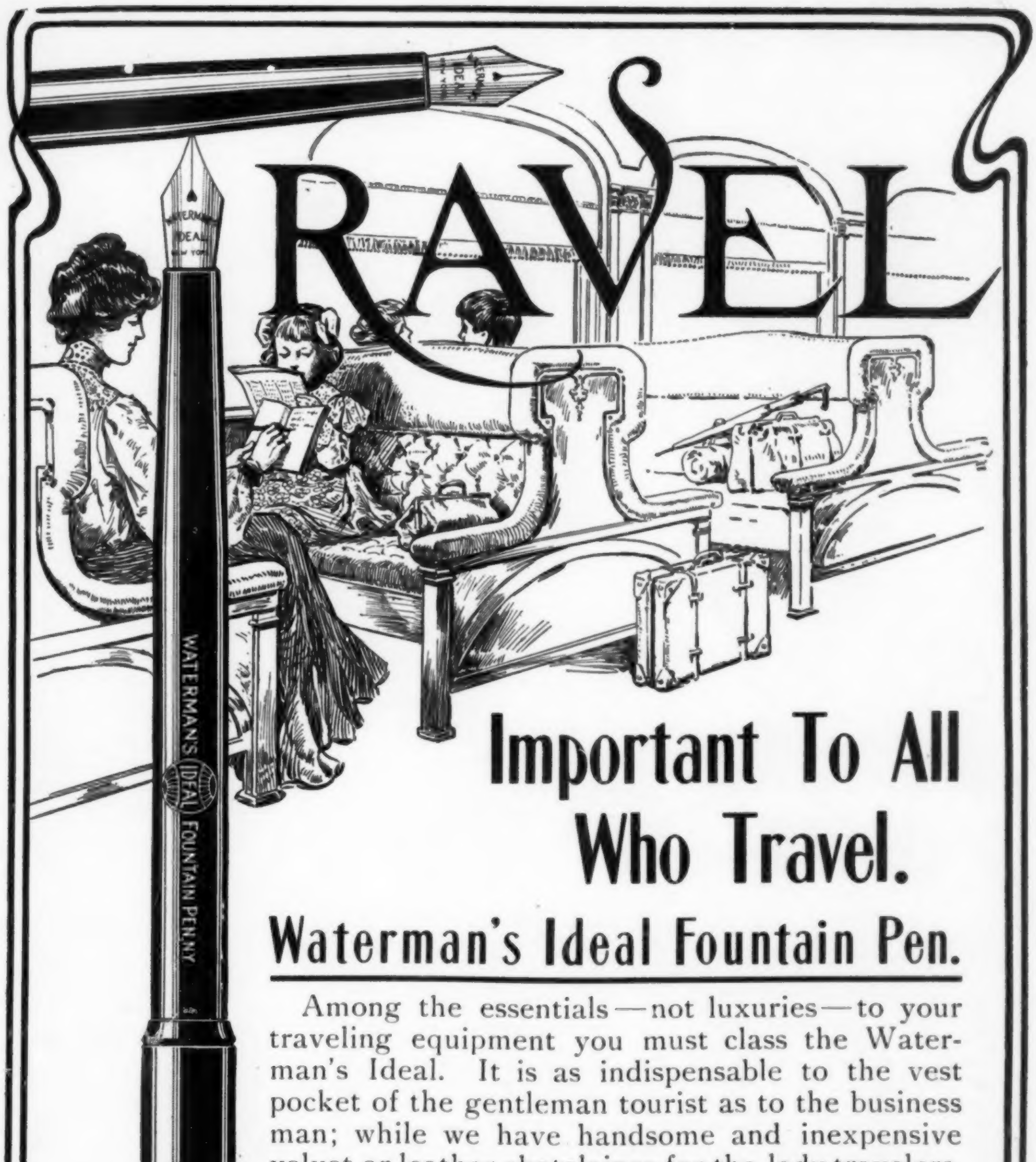
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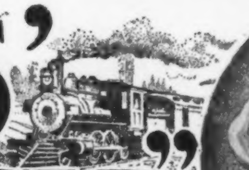

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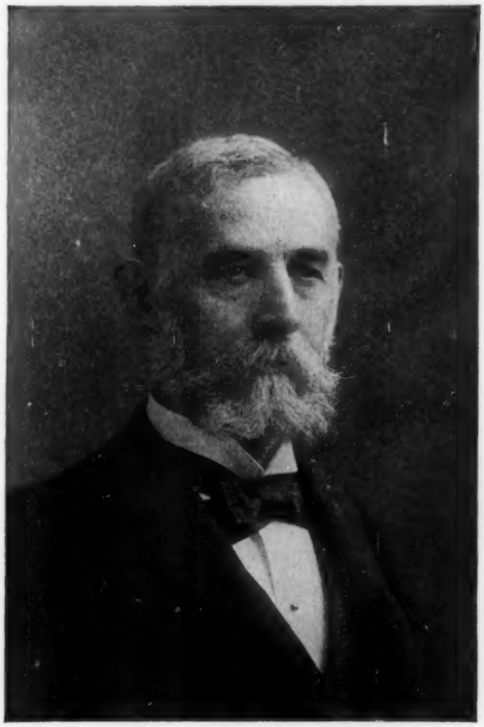
THE HILL OF TARIK IN AMERICA,

By HERBERT S. HOUSTON.

(*With Photographic Illustrations by Arthur Hewitt.*)

FROM Madeira the ship's course was straight for the Mediterranean. Among those on board, bound for the Orient, were a New York publisher and a bright boy from the West, eager for all the new sights of the Old World ahead. As the land breezes caught the pennant at the masthead, the boy scanned the eastern horizon and he kept it up for hours.



U. S. SENATOR JOHN F. DRYDEN,
President of the Prudential.

"What are you looking for so hard?" inquired the publisher.

"Oh, I want to see that big sign of the Prudential on Gibraltar," and the boy still peered into the east. When at last the great rock, the Hill of Tarik the Saracen, lifted its head above the ocean, the boy searched in vain for the sign he was sure he would see. For him, as for all other Americans who read the magazines, the Prudential was inseparably associated with Gibraltar. And this association has made the rock and the insurance company almost interchangeable terms, simply because each suggested strength. But the American Gibraltar achieved its strength in a few years by dauntless human endeavor, while the slow accretions of ages gave strength to its namesake, the mighty Hill of Tarik.

Ten years after the close of the Civil War—a period so recent that its history has scarcely been written—the Prudential was established in Newark. As if foreknowing the great rock to which it would grow, it began its foundation in a

basement office. It was like the beginning of the New York *Herald* by Bennett, the elder, in a basement on Ann Street. But it would be an idle play with words to make a basement office the real foundation of the Prudential. It was something much deeper down than that—nothing else than the bed-rock American principle of democracy. The Prudential applied the democratic principle to life insurance. As Senator Dryden, of New Jersey, the founder of the company, has said: "Life insurance is of the most value when most widely distributed. The Prudential and the companies like it are cultivating broadly and soundly among the masses the idea of life-insurance protection. To them is being carried the gospel of self-help, protection, and a higher life."

HOME OFFICES, PRUDENTIAL INSURANCE CO., NEWARK, N. J.

And what has been the result of the democratic American principle worked out in life insurance? In 1875 the first policy was written in the Prudential. At the end of 1903 there were 5,447,307 policies in force on the books of the company, representing nearly a billion dollars. The assets in 1876 were $2,232, while twenty-seven years later, in 1903, they were more than 30,000 times greater, or $72,712,435.44, the liabilities at the same time being $62,578,410.81. This is a record of growth that is without precedent in insurance and that is hard to match in the whole range of industry. The rise of the Prudential to greatness reads like a romance in big figures, but, in fact, it is a record of business expansion that has been as natural as the growth of an oak. To say that, in ten years, the company's income grew from something more than $9,000,000 a year to more than $39,000,000 last year is amazing as a general statement, but when made in relation to the broad principles on which that growth has been based, there is no mystery about it; but there is in it, from the day when the principles were planted in Newark until these great harvest days, the genuine American spirit of achievement, strong, hopeful, and expansive.

The Prudential Insurance Company of America is a national institution. It was founded to provide insurance for the American people on the broadest possible basis, consistent with strength and safety.

Just as Grant and Lee organized their armies, or as Kouropatkin and Yamagata plan their campaigns in Asia, so does the Prudential work out its national insurance propaganda. The company's organization is essentially military. It is a wonderful combination of big grasp and outlook, with the most painstaking thoroughness and system in details. And, as is always the case in every organization that throbs throughout with intelligent energy, there is a man at the center of it. This man has a constructive imagination lighting up a New England brain. To business prudence there is added the large vision which sweeps the horizon for opportunity. Naturally, to such a vision the application of the democratic idea to insurance was an opportunity of the first magnitude. When seen, it was grasped and developed. The Prudential was founded. Year after year the company added to its number of policy-holders. And all the time the company was working out a more liberal basis for its democratic idea. But each time a more liberal policy was offered, it was fully tested. "Progress with strength" is the way President Dryden describes the company's principle of growth—the results, clearly, of vision and prudence. At the end of ten years of this method of growth, the company reached the point where, it was believed, insurance could be safely offered for any amount with premiums payable on any plan, either in weekly instalments or at longer periods. Within the five years, 1886 to 1890 inclusive, the company's assets increased nearly fivefold, from $1,040,816 to $5,084,-895, and the amount of insurance in force from $40,266,445 to $139,163,654.

ENTRANCE TO MAIN OFFICES.

The Prudential had found itself. The idea of democratic insurance had been fully tested and adjusted to the needs and conditions of the American people. Then, with a boldness which only large vision could have quickened, the plan was formed to make the Prudential's idea known in every section of the country. Gibraltar was chosen as the symbol of the company's strength, and advertising—the telling of the Prudential idea to the people—was begun.

THE HILL OF TARIK IN AMERICA

There is no place where one feels the greatness of the Prudential quite so much as in the vast granite piles which have been raised for the company's home buildings. They rise above the Jersey meadows as Gibraltar does above the sea, a convincing witness, surely, to the growth and to the strength of the Prudential. But they are not a cold, gray rock, but a living organism throbbing from vital contact with millions of policy-holders. There are now four of these great buildings, all occupied by the company.

Today the Prudential is paying over 300 claims a day, or about forty each working hour. On many policies settlement is made within a few hours by the superintendent of the district; on the large policies a report is sent immediately to the home office and settlement authorized by telegraph. And on over 45 per cent. of the claims more money is paid than the policy calls for. From the beginning the Prudential has followed lines of great liberality.

It would be interesting to describe the broad activities that hum in the great buildings at Newark, but they would more than require an entire article themselves. So, too, with the equipment and furnishing of the buildings which, in the way of complete adjustment to their particular work, are probably unequaled in the world. Thousands who go to the World's Fair at St. Louis will find in the Prudential's exhibit in the Palace of Education a fine model of all the buildings, and also the fullest data concerning life insurance that have ever been brought together.

But the last word about the Prudential is not told at any exposition. It is found in the 5,500,000 policies which form a stupendous exhibit on the value of life insurance in developing thrift, safe investment, and home protection in a nation. Of course, such an exhibit could never have been possible if the Prudential had not worked out safe policies that would meet the broad needs of the American people.